

# {In Archive} Comments on draft drinking water PAGS

Stuart Walker to: Edward Tupin

Bruce Means, John Mackinney, Schatzi Fitz-James, Carl Pavetto,

JoAnn Griffith

From:

Stuart Walker/DC/USEPA/US

To:

Edward Tupin/DC/USEPA/US@EPA,

Cc:

Bruce Means/DC/USEPA/US@EPA, John Mackinney/DC/USEPA/US@EPA, Schatzi

Fitz-James/DC/USEPA/US@EPA, Carl Pavetto/DC/USEPA/US@EPA, JoAnn Griffith/DC/USEPA/US@EPA

Archive:

This message is being viewed in an archive.

Hi Ed, I finally was able to review ORIA's draft drinking water PAGs, and get some feedback from other OSRTI staffers. By the way, what is the status of this document?

First, here are my redline/strikeout-suggested changes and <u>[explanatory comments]</u> on the draft water PAGs chapter and draft appendix.



Ch4-3-21-03\_Stuart\_rd1.wpd appG-3-20-03 draft\_Stuart\_rd1.wpd

When I looked at Table 4.2, the concentration numbers seemed high. I put together 3 Lotus 123 Tables comparing ORIA's PAG concentrations to MCLs and concentrations corresponding to a 1 x 10-4 cancer risk. I used MCLs and 10-4 since these are measures EPA utilizes when making decisions about providing bottled water during emergencies involving class A carcinogens. I noticed that a number of the ORIA PAG concentrations are thousands of times higher than the MCLs or 1 x 10-4 (a few are over a hundred thousand times higher). This is not evident without looking at the concentrations since the MCL for most radionuclides is 4 mrem/yr and the PAG is 500 mrem/yr. However, I understand that different science may have something to do with it since the MCL is based on ICRP 2 methodology, the PAG is ICRP 26/30 methodology, and the 1 x 10-4 risk based concentrations are based on ICRP 60/72.

Second, here is an explanation of the comparison tables I put together and the 3 tables themselves









03/04/2004 03:59 PM

ExplainCompareTables.wpd CompareTable\_byRad.123 CompareTable\_byRisk.123 CompareTable\_byMCL.123

Do you see any technical problems with my rough comparison of PAG concentrations with MCLs and 1  $\times$  10-4 cancer risk concentrations? My management was wondering how we are going to justify allowing consumption of potentially much higher concentrations of radiologically impacted water than we generally would during an emergency being addressed under CERCLA.

Edward Tupin/DC/USEPA/US@EPA



Edward Tupin/DC/USEPA/US@ EPA

09/12/2003 08:44 AM

To: Stuart Walker/DC/USEPA/US@EPA

cc: Bruce Means/DC/USEPA/US@EPA, Charles

Sands/DC/USEPA/US@EPA, Colby Stanton/DC/USEPA/US@EPA,

Frank Marcinowski/DC/USEPA/US@EPA, John Mackinney/DC/USEPA/US@EPA, Jonathan Edwards/DC/USEPA/US@EPA, Schatzi Fitz-James/DC/USEPA/US@EPA

Subject: Re: Request for PAGS

Stuart, Here is the March draft of the water PAG, which is the one OW reviewed. I also included Appendix G, which is the more detailed technical material related to water. I'll send the revised version when I have finished revising to address the comments.

(See attached file: appG-3-20-03 draft.wpd) (See attached file: Ch4-3-21-03.wpd)

Ed
Edward A. Tupin, MS, CHP
Health Physicist
Center for Radiological Emergency Preparedness, Prevention and Response
US Environmental Protection Agency
501 Third St. Mail Code 6608J
Washington, DC 20460
(202) 564-9383

1 Stuart Walker redline/strikeout suggested changes and [explanatory comments]

2 **CHAPTER 4** WATER

#### 4.1 Introduction

3

4

5

6

7

8

9

21

22

23

24

25

29

30

31

32 33

34

# What will this chapter tell me?

During a nuclear emergency, it is possible that your surface water supplies may become contaminated. This may be caused by radionuclides deposited from the air as the plume moves through an area or from accidental radioactive spills. Rivers, lakes,

- 10 11 reservoirs, and any other type of surface
- water supplies can be most easily affected. 12
- 13 Some accidents could contaminate
- 14 groundwater, but this is much less likely to
- 15 occur. This chapter identifies the projected
- During a nuclear emergency, you may have to take action to protect your water supplies, including surface water and ground water sources. Surface water includes any water that systems pump and treat from sources open to the atmosphere, such as rivers, lakes, and reservoirs. Ground water is water that systems pump and treat from natural reservoirs below the earth's surface known as aquifers.
- level of radiation exposure at which protective actions are initially needed to protect the public 16
- 17 from using water contaminated with radioactive material. This chapter also provides you with
- 18 the concentrations of radionuclides in water that correspond to EPA's Protective Action Guide
- 19 for Water. This will assist you in carrying out these protective actions.

#### 20 What is a Water Protective Action Guide (PAG)?

A protective action guide tells you when you should take action to prevent, reduce, or limit a person's radiation dose from an unplanned release of radioactive material into the environment. A person can

The amount of radiation people absorb is called a **dose**. The way they may be exposed is called an exposure pathway.

26 receive a radiation dose when using contaminated water. Thus, a water protective action guide 27 tells you when you should take action to prevent people from using contaminated water, based 28 on the projected radiation dose. The Water PAG is expressed as a numerical dose level.

# What is the water protective action quide recommended by the U.S. EPA?

EPA recommends a water protective action guide of 0.5 rem total effective dose equivalent for the first year of exposure. This PAG is not intended to set an acceptable level of exposure to the public, nor is it intended for use at site cleanups occurring under other statutory authorities such as EPA's Superfund program, the NRC's decommissioning program or other federal and state cleanup programs as a cleanup level.

# How was the water protective action guide determined?

EPA looked at several issues in determining the water protective action guide. First, we considered when, in the sequence of a nuclear incident, it would be necessary to take action to protect drinking water supplies. Because it will take some time after the radioactive plume passes to determine the full extent of any

1

2

3

4

5

6

7

8

9

12

13

14

15

16

17

18

19

20

21

22

23

2425

26

27

28

29

30

31

32

33

34

35

36

37

38

39

40

Chapter 3 of this manual recommends that, during the intermediate phase of a nuclear incident, you should concentrate your clean up efforts in areas in which the projected dose from the first year of exposure exceeds 0.5 rem. EPA chose to make the Water PAG consistent with this guidance.

contamination to surface water bodies, we assumed that actions to protect drinking

water supplies would likely be put in place during the intermediate and recovery phase of a nuclear incident. In fact, it is unlikely that emergency response personnel will have the results from radiation measurements of water supplies until well after the plume has passed.

Chapter 3 of this manual provides a detailed discussion of a variety of protective actions that you should consider taking during the intermediate phase of a nuclear incident. EPA has set the water protective action guide at a level consistent with the recommendations given in Chapter 3.

We also looked at guidance issued by other organizations, as well as by other parts of EPA, in developing the Water PAG. In this chapter, we are recommending a water protective action guide of 0.5 rem total effective dose equivalent. Using EPA's estimate of radiogenic cancer risk (Estimating Radiogenic Cancer Risk, EPA 402-R-93-076, June 1994) a one-year exposure of 0.5 rem (beta-photon, alpha exposure would be less) produces an individual lifetime cancer incidence risk of slightly above 10<sup>-4</sup>. In other words, a person who received a radiation dose of 0.5 rem in one year would experience a risk of developing cancer sometime during his or her lifetime of about 4 in 10,000, due to the radiation exposure received. [For risk assessment, EPA has traditionally used FGR 13 risk coefficients for MCLs and HEAST slope factors for CERCLA. There was no reason to use a simplified and inaccurate dose to risk conversion when EPA could develop risk estimates for each isotope] EPA has used a risk level of 1 in 10,000 to guide the clean up of sites contaminated with radiation or other hazardous materials under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). In addition, tThe International Commission on Radiological Protection recommends intervention efforts following a nuclear emergency at a dose level of 0.5 rem. Thus, the Water PAG is consistent with both national and international guidance related to nuclear incidents and the clean up of contaminated sites. [The CERCLA document most analogous to this PAG would be the "Final Guidance on Numeric Removal Action Levels for Contaminated Drinking Water Sites" OSWER 9360.1-02, October 25, 1993, which discusses when short-term risks from contaminated drinking water wells are high enough to warrant providing alternative (replacement) drinking water supplies. For class A carcinogens that do not have DWELs or longer-term HA's, like radionuclides, this guidance says to provide

# <u>drinking water if the concentrations are above $1 \times 10^{-4}$ lifetime risk (using OW methodology of 70 year exposure)</u>, or the MCL, if the MCL is greater than $1 \times 10^{-4}$ lifetime risk. ]

We consider that this dose and risk level will provide an acceptable level of safety to an affected community for the first year following a nuclear incident (intermediate phase). We should emphasize that you must evaluate the need for intervention and an appropriate levels of exposures after the first year. Lifetime exposures at 0.5 rem/ year will result in high risk. Interventions (like those explained in section 4.2) implemented after the first year can significantly reduce exposures. Depending upon your individual circumstances, you should choose an appropriate dose level and remedial action for the long-term. Chapter 6 (Recovery Phase) provides a framework for choosing appropriate long-term risk levels and remedial actions.

# Should I prevent people from showering and bathing with contaminated water?

As you can see in Appendix G, EPA examined the potential radiation dose people could receive from various uses of contaminated water, including showering and bathing. For almost all radionuclides, these activities represented a smaller risk than did drinking contaminated water. *[using CERCLA methodology (DDC calculator), H-3, Ra-224, and Ra-226 would pose a significant inhalation risk]* In addition, people typically shower and bathe using the same source of water that they use to drink. Because of this we do not recommend that water meeting the PAG from showering and bathing be used while a separate, cleaner water source is supplied for drinking. Thus, if you protect your community's drinking water supply, you will be protecting the source of water that people use for virtually all of their needs.

# Does the Water PAG also apply to ground water supplies?

1 2

Most nuclear incidents will affect surface water supplies. Some accidents could contaminate ground water, but this is much less likely to occur. In addition, the time it would take for ground water to become contaminated would be sufficient to plan for and implement protective actions. The Water PAG does apply to ground water; however, it is really intended to guide your planning and decision making during the early and intermediate phases of a nuclear emergency when surface water supplies are particularly vulnerable to contamination from deposition of radioactive materials from the air.

# Is the water protective action guide different from the other protective action guides presented in this manual?

No. The water protective action guide is consistent with the dose level recommended for clean up relocation during the intermediate phase of a nuclear incident (Chapter 3) and the dose level associated with the food protective action guide presented in Chapter 5. <u>[Note, it is much easier to provide new food and water than relocate someone. This rationale may not go over well with the public.]</u>

#### **Applying the Water PAGs** 4.2

# When should I take action?

1

2

- 3 If you suspect that your water supplies may be affected by a nuclear emergency and that 4 projected radiation doses from drinking contaminated water could exceed 0.5 rem in the first
- year, you should consider taking actions to protect your community's drinking water. 5

#### 6 What actions should I take?

7 EPA has examined seven possible actions to protect drinking water. These are summarized in Table 4-1 and discussed in detail below. 8

2	Wait for Flow-By							
3	Ration Clean Water Supplies							
4	Treat Contaminated Water							
5	Activate Existing Connections to Neighboring Systems							
6	Establish Pipeline Connections to Closest Sources/Systems							
7	Import Water in Tanker Trucks							
8	Import Bottled Water							

# 9 Option 1: Wait for Flow-By

If radionuclides are deposited from the atmosphere over a river, a section of the water can become contaminated. As it flows down the river, this section of contaminated water is called a plume. (This is similar to the atmospheric plume of radiation described in Chapter 1.) Option 1 calls for closing down any source intake valves along the path of the plume of contaminated water. While the intake valve is closed, no contaminated water can enter the water supply system. During this time, you can depend on the system's existing storage capacity. (Large systems usually possess 12 to 24 hours of water storage capacity.) If the stored water supplies could be depleted before the affected valves can be reopened, you should consider treating the contaminated water while you are using your available stored water supplies. This assumes that you have the treatment technology in place or readily accessible. If you had no other option, you could temporarily replace contaminated water with large quantities of purchased uncontaminated water.

#### Option 2: Ration Clean Water Supplies

Rationing uncontaminated water is also a possibility. This is particularly true if water reserves can provide each individual in the community with 1 liter (about 1 quart) of water per day until the contaminated plume has passed, the contaminated water is treated, or the water supply system has returned to normal operating conditions. If you choose to ration water, you should be sure that the contamination is isolated from the system or is in a single area of the system and that you have efficient methods for rationing in place. Rationing water might also be required if your water treatment capabilities are limited. You may want to consider a scheme to ration water as part of your emergency planning efforts.

#### Option 3: Treat Contaminated Water

Various treatment options exist for reducing or eliminating the contamination of drinking water by man-made radionuclides. According to a 1986 survey of community water supply systems though, fewer than 10 percent of all water systems treat specifically for radionuclides.

- 1 However, typical technologies used to treat water for other contaminants can reduce the
- 2 concentration of radioactivity. These technologies include coagulation/filtration, ion exchange,
- 3 lime softening, and reverse osmosis. Their actual removal efficiency depends on the
- 4 radionuclide and the type of treatment. For example, ion exchange can remove up to 99 percent
- of strontium-89, strontium-90, cesium-134, cesium-137, iodine-131, and cobalt-60 from
- 6 contaminated water (HE-85). (These are the radionuclides that you are most likely to be
- 7 concerned about in the event of a nuclear emergency.) Similarly, reverse osmosis can be used to
- 8 effectively remove alpha-emitting radionuclides, such as plutonium-239, from the water supply
- 9 (HE-85). [Should note that those radionuclides will become concentrated in the treatment
- 10 <u>residuals (sludge, etc), and special operating procedures and disposal procedures will be</u>
- *needed.*]

# Option 4: Activate Existing Connections to Neighboring Systems

If the water supply system is part of a larger, regional supply system, you may want to consider activating existing connections to a neighboring area. Most large water systems can establish connections with other large systems for emergency purposes. In fact, you may have already considered this option as part of your emergency planning. If you implement this option, you must take steps to ensure that the "clean" systems do not become contaminated from water backflow.

If you are protecting a smaller water supply system (i.e., one that serves between 10,000 and 75,000 people) or reside in a sparsely populated or rural area, you may not be connected to a neighboring system. In this case, you may want to explore the possibility of regionalization as part of your emergency planning strategy. This involves connecting smaller systems to larger systems, thus forming a regional water supply system. This is obviously a long-term proposition, but it does have the added advantage of reducing system vulnerability to water shortages or water quality problems other than those resulting from a nuclear emergency.

## Option 5: Establish Pipeline Connections to Closest Sources/Systems

Running a pipeline from a "clean" water supply system to various distribution centers located throughout the affected community is a routine means of providing clean water. For example, when water mains must be repaired or cleaned of debris, community water needs have been met through the assembly of temporary pipes and hoses. This is a relatively simple procedure, requiring very little construction and technical expertise. For medium- to long-term emergencies, the construction of a temporary pipeline could be cost-effective. PVC pipe, fire hoses, and steel pipe have been used to provide emergency drinking water for periods of up to two months when service has been disrupted by earthquakes, drought, or bacterial contamination.

#### Option 6: Import Water in Tanker Trucks

If an uncontaminated source of water is close to the affected area, it may be more efficient for you to arrange to transport water from that source by truck, rail, or barge to distribution centers located throughout the community. The most significant obstacle for the use of this option is the cleanliness and availability of transport vehicles. State and local laws may also affect this option.

# Option 7: Import Bottled Water

1 2

You may also import bottled water into the affected community. <u>[Note, this will not provide water for bathing, showering, running dishwashers.]</u> The water may come from a nearby water supply system or from a local spring water bottling company. This option may be cost-effective during an emergency if water is needed quickly and if the length of the emergency does not merit long-term action, such as the construction of a temporary pipeline.

Any of the actions just described may be taken alone or in combination, depending on the nature of the emergency and the characteristics of your local water system. These seven options are outlined in this manual to allow you to consider them and determine which, if any, are the most practical to implement in the face of an actual emergency. Figure 4.1 will help you consider the various options. By considering these options now, you have the opportunity to develop state and local emergency plans and implementation procedures that reflect the unique needs of your particular community. Advance planning can reduce the stress of making key decisions quickly during a nuclear emergency.

# How will I know that the protective action is effective?

Each of the protective actions just described will take some time to implement. As a result, contaminated water may reach the affected population. Protective actions directed at the water supply, such as valve closures and water treatment, will reduce the

likelihood that people will be exposed to

Your emergency response plan should include a radiological surveillance program to monitor the effectiveness of the actions you take to protect water supplies.

contaminated water. However, these options may not be fully effective or may not be available to you.

To ensure that the protective actions you take are effective, your emergency response plan should include a comprehensive radiological surveillance program. This program will monitor the concentration of radionuclides in the drinking water and will give you an indication of whether the actions you are taking are effective. Your emergency response plan should also include a strategy for keeping the community informed of the actions being taken and ensuring that people understand their role in carrying them out.

## How will I know when to terminate the protective actions?

Your radiological surveillance program should give you part of the information needed to make this decision. You can suspend protective actions once you are sure that people will not be

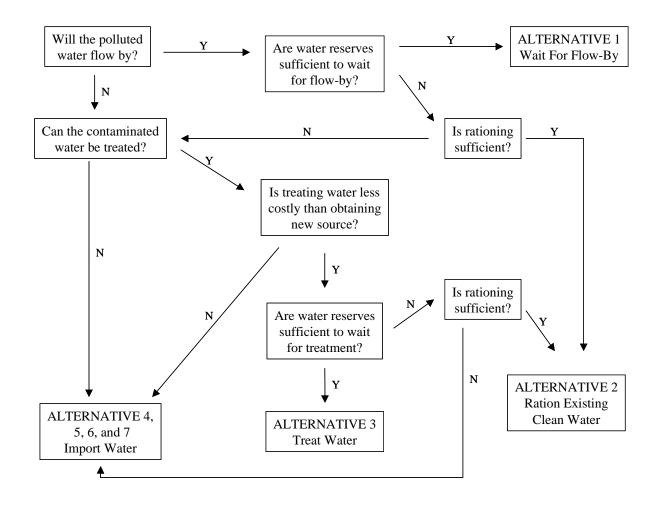


Figure 4-1 Decision-Making Sequence for Providing Uncontaminated Drinking Water

exposed to radiation levels from drinking contaminated water that exceed the Water PAG. You will base this decision not only on the information you have at the time, but also on your understanding of how conditions may change in the future. In certain situations, contamination can occur episodically, over a long period of time [Note that this very important possibility is not included in the Figure 4.1 decision chart]. For example, if a watershed is contaminated as a result of a nuclear emergency, a plume of contamination may move through the water system with the runoff following each rainfall. You may be reluctant to eliminate protective actions until you can be sure that such episodes of contamination are over. The Federal Emergency Management Administration can help you make these decisions through its Federal Emergency Response Program.

# 4.3 Projecting Radiation Doses Using Derived Response Levels (DRLs)

# What are Derived Response Levels (DRLs)?

The use of Derived Response Levels (DRLs) will allow you to compare the concentration of radionuclides in your

drinking water to the Water PAG of 0.5 rem.

7 In other words, a DRL is simply the

8 concentration of a particular radionuclide that

**Derived Response Levels (DRLs)** are measured levels of radionuclide concentrations in drinking water indicating that, without protective actions being taken, the Water PAG may be exceeded.

- 9 equates to a 0.5 rem radiation dose level for the first year. Your radiological surveillance
- program will provide you with information regarding the concentrations of various radionuclides
- in your drinking water. You can then use this information, along with the tables provided in this
- chapter, to determine whether the Water PAG is likely to be exceeded.

## What DRLs should I use?

Under ideal circumstances, you would derive event- and site-specific DRLs based on the unique characteristics of the nuclear emergency that has occurred and your community's water system. However, such calculations could be difficult and time-consuming, requiring large amounts of data and specialized expertise in hydrology and water resource management. Instead, EPA has developed generic DRLs for use in your emergency planning and response activities. You may also use these generic DRLs during an actual emergency, until you have the time or the need to develop event- or site-specific DRLs.

Table 4-2 presents generic DRLs for radionuclides likely to contaminate a water supply during a nuclear emergency. This is the same list of radionuclides included in Chapters 2 and 3, with the exception of the very short-lived nuclides and the noble gases. (These latter nuclides are unlikely to get into the water supply.)

The last four columns in Table 4-2 represent different rates at which the radionuclide concentration is assumed to decline over a one-year period. The column labeled "without radioactive decay" assumes that the radionuclide concentration in the water supply stays constant over a one-year period. <u>IIn attached Lotus 123 file, these values were compared to MCLs and 1 x 10<sup>-4</sup> cancer risk since these are most analogous to how CERCLA analyzes contaminated water!</u> This is the most conservative assumption and is based on the premise that a continuing source of contamination exists that maintains the radionuclide concentration in drinking water at a constant level for one year. The column labeled "with radioactive decay" assumes that the radionuclide concentrations in the water supply decline by virtue of radioactive decay only. These are also conservative values. The column labeled "reservoir scenario" assumes that the radionuclide concentrations in the water supply decline not only due to radioactive decay, but also due to a daily reservoir depletion rate of 0.19 percent (SC-93). This is a more realistic scenario because it accounts for both radioactive decay and the rate of turnover of water in the reservoir. The last column, labeled "river scenario," assumes that the

radionuclide concentrations in water decline due to radioactive decay and to a watershed 1 2 depletion rate of 0.99 percent per day (SC-93). This scenario would apply to situations 3 involving a contaminated watershed and represents a continuing source of contamination due to runoff. [CERCLA decisions on whether to provide drinking water are generally made on the 4 5 basis of current concentrations, not on modeling that assumes depletion rates or extent of 6

source]

7

8

9

10 11

12

13 14

15

16

In all four scenarios, EPA derived the DRLs by calculating the radionuclide concentrations in water that will result in a radiation dose of 0.5 rem total effective dose equivalent in the first year, assuming the members of the exposed population each consume 2 liters of water per day for an entire year. Table 4-2 includes different sets of values to allow you to consider the range of different environmental depletion rates that may be associated with a given event at a given site. The actual set of DRLs you use will depend on the unique characteristics of the situation with which you are dealing at the time. If you are uncertain of the environmental conditions that may help reduce radionuclide concentrations in the water supply, you may choose to use the "without radioactive decay" scenario, because it will provide the most protection until you have an opportunity to gather additional information.

#### 17 How were the DRLS derived?

18 The DRLs may be calculated using the following formula:

#### 19 where:

28

29

30

31

32

33

20 DRL = the derived response level (picoCuries per Liter); 21 Η = the PAG (mrem) 22 L = the effective decay constant (sum of the radioactive decay constant and the 23 removal constant due to natural processes, expressed as the fraction of 24 contamination removed per day) 25 = dose conversion factor (mrem/pCi ingested, derived from EP-88) h 26 T = exposure time or interdiction time (days) =  $\frac{1}{2}$  year 27 I = the daily water intake (liters/day)

This formula assumes that the initial event has contaminated a reservoir uniformly and that the activity in the reservoir declines with an effective half-life that reflects radioactive decay and the natural depletion of the radioactivity in the system [Including the watershed?].

This equation simplifies the removal of radiation from a water supply following a contaminating incident. For example, if a nuclear accident results in the contamination of the water in a reservoir, then the radionuclide concentration will decline with the effective half-life of the radionuclide in the reservoir. The equation also considers the turnover rate of the water in the reservoir, which typically has a one-year half-life. Accordingly, L, in the above equation, equals the sum of the radioactive decay constant and the water removal constant, which by definition equals 0.693/365 days for a reservoir with a one-year half-life.

Contamination of a watershed from a radioactive spill or fallout would present a much more complex situation. Under this scenario, the concentration of the radionuclides in the reservoir immediately following the accident would change in a complex, cyclic manner, reflecting the rate at which radionuclides are leaving the reservoir and the rate at which radionuclides are entering the reservoir from runoff from the watershed. In this case, the timevarying nature of the concentration of the radionuclides in the reservoir is highly site-specific and depends heavily on the rainfall pattern and intensity. Nevertheless, in the long term, the rate of decline of the radionuclide concentration in the reservoir will reflect the overall rate of decline of the radionuclide concentration in the water from the watershed.

# What specific parameters did EPA use in calculating the DRLs in Table 4-2?

Given the range of possible scenarios, a number of options exist for deriving the response levels based on this equation. The simplest approach is to assume that the radionuclide concentrations observed in the reservoir remain constant. You may also assume that L, the effective decay constant, is equal to either: (1) the radioactive decay constant or (2) the sum of the radioactive decay constant and a reservoir depletion rate constant. This is the case for large reservoirs with relatively low turnover rates. For rivers (and for small reservoirs with high turnover rates), the radionuclide concentrations will likely reflect both radioactive decay and watershed depletion rates. You could also calculate DRLs based on site-specific data. Each of these approaches will influence the value of the DRLs, which in turn will influence your strategy for implementing the Water PAG.

The DRLs are also affected by the assumed exposure time, T. In this analysis, T is assumed to be one year. This selection coincides with the estimated average depletion rate for reservoirs where the half-time is about one year (SA-64). The longer the assumed exposure time, the lower the DRLs.

The assumed water intake rate. I. is another variable that will influence the DRLs. Two options exist. You can assume a water intake rate of 1,400 milliliters per day (mL/day), which is the average among U.S.

adults (EP-89). [Hard to see the justification

In developing the DRLs contained in Table 4-2, EPA assumed an exposure period of one year, a water intake rate of 2,000 mL/day, and dose conversion factors recommended by Federal Guidance Report No. 11.

for changing EPA default input parameter 35

1 2

3

4

5

6 7

8

9

10

11

12

13

14

15

16

17 18

19

20

21

22

23

24

25

26

27 28

29

30

31

32

33

34

used across various programs.] You could also use a value of 2,000 mL/day, which represents 36

the water intake of the upper 90<sup>th</sup> percentile of the U.S. population (EP-89). This latter value 37

provides an increased margin of safety to account for the greater radiation sensitivity of children 38 39

whose tap water intake is about one-tenth to one-third of this value (EP-84).

# How do I address the uncertainty associated with contamination of a watershed?

The largest single source of uncertainty in deriving DRLs for contaminated water results from the radioactive contamination of a watershed, which in turn results in the contamination of water resources. Uncertainty results from a lack of specific information about the rate at which the water supply is contaminated by runoff and percolation from the contaminated watershed, as well as the associated uncertainty in the time-varying concentration of radionuclides in water supplies.

Developing a reasonably accurate model for predicting the movement of radionuclides from a watershed to their ultimate fate in a reservoir or other water body is a very difficult problem. The uncertainty of precipitation events represents a major obstacle to credibly predicting this movement. Rain may fall in almost any pattern of frequency and intensity.

[Historical data is available for each location] This leads to great uncertainty in predicting the magnitude of dilution in streams and lakes, the lateral movement of a contaminant due to erosion, or the vertical movement of a contaminant due to percolation in a watershed.

Removal of radionuclides from a watershed occurs episodically. Following a contaminating event, the first storms of large volume and intensity would introduce the largest pulse of radioactivity into the receiving waters in the watershed, including the reservoirs. Each subsequent rainfall will likely contribute diminishing amounts of radioactivity. Consequently, the watershed depletion rate is best expressed as a generally declining rate of depletion. As a result, the radionuclide concentrations in a reservoir may be expected to vary significantly from day to day. However, over the long term (i.e., several months), the average radionuclide concentrations in the reservoir may be expected to decline with the average radionuclide concentrations in the water in the watershed.

If you know that a watershed has been contaminated by a nuclear accident, you should use the most conservative DRLs in Table 4-2 that apply to the "river scenario," unless you have site-specific or event-specific data. You may also choose the most conservative option and implement protective actions based on the "without radioactive decay" DRLs. Whatever you choose, it is important that you have a radiological environmental surveillance program in place to collect up-to-date information concerning the concentrations of radionuclides in your water supplies.

# How did EPA determine the environmental depletion rate?

In communities of 25,000 or more, the initial source of drinking water is generally from a large, open impounding reservoir. The water is removed from this reservoir and placed in smaller reservoirs as raw water at the water treatment plant. After If filtering and chlorination [Don't believe that all systems do this] have been accomplished, the water is stored in closed tanks to prevent contamination prior to entering the distribution mains in the municipality (SA-64). In an attempt to illustrate how an impoundment might behave over time, EPA used the parameters typical of the Occoquan Reservoir in Virginia to estimate the holding time for the

reduction of concentrations of strontium-90 and cesium-137 (BE-91). The Occoquan Reservoir serves about 140,000 people (SA-64).

In conducting this analysis, EPA evaluated two different scenarios. The first assumed the reservoir was in the path of an airborne radioactive plume with radioactivity being deposited directly on the water, as well as into the watershed. The second scenario assumed that the plume missed the reservoir, but deposited radioactivity into the watershed. The results of this study showed that reductions in the soluble concentrations of radionuclides over time were more related to the regulation of the reservoir (inflow/outflow) than to the sedimentation process. In both cases, the half-life of the reservoir was approximately 15 days; however, the regulation of the reservoir was assumed to be 4.7 percent each day. This is an unusually high value for a large potable water supply. The average regulation is about 0.2 percent per day (SA-64). If you assume the lower, and more realistic, rate of change, then the half-life for the reservoir increases to about one year for routine operation. [Seems unrealistic to assume that operator would not shut off the outflow from a reservoir that was contaminated. Downstream neighbors at the least would not be happy with plume moving towards them]

EPA chose a one-year half-life for the environmental depletion rate because it represents an upper end for the half-life and results in DRLs that provide a high level of assurance that the PAG will not be exceeded (see Appendix G). For water supply systems and/or contaminating events that have a significantly shorter half-life, the DRLs will be overly conservative. Under these circumstances, you may choose to develop site- or event-specific DRLs. Alternatively, if in the unlikely event that the depletion rate of the radionuclides in the reservoir has a half-life longer than one year, DRLs based on an assumed one-year half-life could result in doses exceeding the PAG. You should monitor the rate of decline in radionuclide concentrations, and, if it is declining at a slower rate or increasing, implement protective actions as necessary.

# How did EPA choose the one-year exposure time?

The one-year half-life depletion rate also provides a rationale for the selection of a one-year exposure time. This exposure period assures that protective actions would be in place long enough for water monitoring to reveal a decline in the concentrations of radionuclides in the drinking water supply and/or other variables affecting the potential radiation dose to members of the community. Using a one-year basis for the DRLs also reduces the uncertainty due to the inability to predict the temporal variations in rain storm events over a shorter period.

# Did EPA factor the removal of radionuclides by water treatment into the calculation of DRLs?

Although effective treatment options exist for removing radionuclides from drinking water, EPA did not consider these options in its calculation of generic DRLs. Because these are generic DRLs, EPA did not think that it was appropriate to make assumptions about the type of water treatment system that might be in place, given the variability in the type and location of water systems that could be affected by a nuclear emergency. However, you may elect to take

treatment into consideration when implementing the PAGs on a case-by-case basis or calculating your site-specific DRLs.

Several routine water treatment options may reduce radionuclides in drinking water. Approximately 50 percent of the water consumed by the U.S. population is treated by a combination of coagulation, sedimentation, and filtration; approximately 85 percent of U.S. water systems depending upon surface water for their supply use this treatment option. [These treatment methods remove suspended solids, not dissolved chemicals]

Treatment may reduce the concentration of strontium-90 by 80 to 90 percent and the concentration of cesium radioisotopes by 50 percent in the final tap water (HE-85). Iodine-131 is reduced by less than 20 percent, rubidium-103 by 70 percent, and cobalt-56 by 60 percent using this treatment option. In addition, 14 percent of the water consumed by the U.S. population undergoes only direct sand filtration, which should remove particulate matter, and, to a much lesser extent, dissolved radionuclides.

More sophisticated water purification methods, such as ion exchange or reverse osmosis, <u>[remove dissolved metals]</u> can produce greater reductions in radioactivity. However, they are usually installed only in systems where a municipal water supply needs softening. They are less likely to be in place at the time of a nuclear accident than are more conventional coagulation/filtration systems. However, ion exchange does offer a relatively easy batch method for post-event decontamination with efficiencies of about 98 percent. [for what?]

# Why did EPA derive generic DRLs?

We derived generic DRLs to help you plan for and, in the event of a nuclear emergency, take protective actions quickly and effectively. Without these values, you would be required to derive site- and event-specific DRLs during an emergency. Although this approach would reduce some of the uncertainty associated with generic DRLs, it would require real-time analysis that might be difficult to obtain or might cause a delay in taking action if time-sequenced data needed to be gathered. However, you may choose to develop site-specific DRLs; the generic values included in this manual are only intended to help you in your decision making. They are not mandatory.

#### How are the DRLs to be used?

You can use the DRLs to trigger and guide your response to an incident that results in, or that could result in, the contamination of drinking water supplies. For example, you might take action to protect water supplies as soon as you are notified of an incident. Data can then be obtained from monitoring programs, and field measurement programs can be expanded to include drinking water samples. Such programs could include sampling and analysis of water upstream and downstream of a water supply system and in storage within the supply system. Samples of soil and sediment within the watershed may also provide useful information. You can compare these data to the DRLs in Table 4-2 and use them to make informed judgments

- 1 regarding the need to implement protective actions. Once you have determined that the potential
- 2 exists for the PAG to be exceeded, you can initiate actions or revise them based on the results of
- 3 comparing your environmental data to Table 4-2. It is important to remember that such actions
- 4 are likely to be site- and event-specific. However, considering various strategies before an
- 5 incident occurs will allow you to make quick and effective decisions when time is of the essence.

# Will I really have time to begin a water sampling program before I will be faced with the need to protect drinking water?

You are likely to have enough time to begin a program of water sampling. In the case of an accident involving a nuclear fuel cycle facility, including a nuclear power plant, it would take some time for radionuclides to be deposited from the plume into the water supply system. This delay would allow you time to establish a monitoring, avoidance, and interdiction (prohibition) program to minimize the effects of the contaminated water (CO-85). In the event of a transportation accident, radionuclides would take some time to dissolve before entering the water supply system. Again, you should have adequate preparation time for emergency measures.

You should begin your water monitoring program upstream of the accident site, preferably before the water intake pipe, and at the watershed, when possible, to act as an early warning system. If sampling results indicate that radionuclide concentrations upstream are high enough to produce tap water that exceeds the Water PAG, you should begin to prepare to implement protective actions. Once you have confirmed excessive radionuclide concentrations by in-plant sampling, first at the raw water storage and then at the treated water storage, you should activate your full complement of emergency measures.

## How do I use the DRLs if there are multiple radionuclides found in the water supply?

If a source of drinking water contains several radionuclides, you should use the sum of the fractions rule, as follows:

where:

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

- F = the sum of fractions
- $C_i$  = the concentration of radionuclide, i, in the water supply (pCi/L)
- DRL<sub>i</sub> = the derived response level for the i<sup>th</sup> radionuclide (pCi/L)

For example, let us assume that, as a result of a nuclear power plant accident, a water supply is contaminated with 100,000 pCi/L of iodine-131, 12,000 pCi/L of cesium-137, and 3,500 pCi/L of strontium-90. The DRLs in Table 4-2 for radioactive decay only are 406,504,

32 13,850, and 4,950, respectively. The sum of fraction rule would result in the following:

2 Based on this, the radionuclide contamination levels exceed the DRL for this 3 combination of radionuclides, assuming depletion by radioactive decay only. As such, a 4 protective action would be recommended. 5 If F is less than one, the contamination is less than the DRL, and there is no need to take action unless the concentrations change. If F is greater than one, the DRL is exceeded. 6 7 Intervention is recommended until such time that the radionuclide concentrations decline below 8 the DRL and that you are sure that the radionuclide concentrations will not increase above the 9 DRL in the future.

F = 100,000/406,504 + 12,000/13,850 + 3,500/4,950 = 0.25 + 0.87 + 0.71 = 1.83

1

10

11

12

Of course you may implement actions to protect your water supply at any time following a nuclear incident. The DRLs are provided as a point of reference to aid emergency response personnel in their decision-making.

Table 4-2. DRLs Associated with a Total Effective Dose Equivalent of 0.5 rem Resulting from One Year of Ingestion

		Dose		Normalize mrem per pCi			DRLs (pCi/L)			
Radionuclide	Radioactive Decay Constant 1/day	Conversion Factor mrem/uCi ingested	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario
H-3	1.50e-04	6.40e-02	4.67e-05	4.55e-05	3.29e-05	1.24e-05	1.07e+07	1.10e+07	1.52e+07	4.03e+07
C-14	3.30e-07	2.10e+00	1.53e-03	1.53e-03	1.11e-03	4.13e-04	3.27e+05	3.27e+05	4.50e+05	1.21e+06
Na-22	7.30e-04	1.10e+01	8.03e-03	7.05e-03	5.16e-03	2.03e-03	6.23e+04	7.09e+04	9.69e+04	2.46e+05
P-32	4.80e-02	8.80e+00	6.42e-03	3.67e-04	3.53e-04	3.04e-04	7.79e+04	1.36e+06	1.42e+06	1.64e+06
P-33	2.70e-02	9.20e-01	6.72e-04	6.81e-05	6.37e-05	4.99e-05	7.44e+05	7.34e+06	7.85e+06	1.00e+07
S-35	7.90e-03	4.50e-01	3.29e-04	1.08e-04	8.93e-05	5.05e-05	1.52e+06	4.63e+06	5.60e+06	9.90e+06
Cl-36	3.80e-04	3.00e+00	2.19e-03	2.04e-03	1.49e-03	5.70e-04	2.28e+05	2.45e+05	3.36e+05	8.77e+05
K-40	1.00e-08	1.90e+01	1.39e-02	1.39e-02	1.00e-02	3.73e-03	3.60e+04	3.60e+04	5.00e+04	1.34e+05
Ca-45	4.30e-03	3.20e+00	2.34e-03	1.18e-03	9.25e-04	4.48e-04	2.14e+05	4.24e+05	5.41e+05	1.12e+06
Sc-46	8.30e-03	6.40e+00	4.67e-03	1.47e-03	1.22e-03	7.02e-04	1.07e+05	3.40e+05	4.10e+05	7.12e+05
Ti-44	4.00e-05	2.30e+01	1.68e-02	1.67e-02	1.20e-02	4.50e-03	2.98e+04	2.99e+04	4.17e+04	1.11e+05
V-48	4.30e-02	8.60e+00	6.28e-03	4.00e-04	3.83e-04	3.25e-04	7.96e+04	1.25e+06	1.31e+06	1.54e+06
Cr-51	2.50e-02	1.50e-01	1.10e-04	1.20e-05	1.12e-05	8.60e-06	4.55e+06	4.17e+07	4.46e+07	5.81e+07
Mn-54	2.20e-03	2.80e+00	2.04e-03	1.41e-03	1.06e-03	4.57e-04	2.45e+05	3.55e+05	4.72e+05	1.09e+06
Fe-55	7.00e-04	6.10e-01	4.45e-04	3.93e-04	2.88e-04	1.13e-04	1.12e+06	1.27e+06	1.74e+06	4.42e+06
Fe-59	1.60e-02	7.90e+02	5.77e-01	9.85e-02	8.81e-02	6.10e-02	8.67e+02	5.08e+03	5.68e+03	8.20e+03
Co-58	9.80e-03	3.00e+00	2.19e-03	5.95e-04	5.06e-04	3.04e-04	2.28e+05	8.40e+05	9.88e+05	1.64e+06
Co-60	3.60e-04	2.70e+01	1.97e-02	1.85e-02	1.34e-02	5.14e-03	2.54e+04	2.70e+04	3.73e+04	9.73e+04
Ni-63	1.90e-05	5.70e-01	4.16e-04	4.15e-04	2.99e-04	1.12e-04	1.20e+06	1.20e+06	1.67e+06	4.46e+06
Zn-65	2.80e-03	1.40e+01	1.02e-02	6.40e-03	4.89e-03	2.18e-03	4.90e+04	7.81e+04	1.02e+05	2.29e+05

Table 4-2. DRLs Associated with a Total Effective Dose Equivalent of 0.5 rem Resulting from One Year of Ingestion (continued)

		Dose		Normalize mrem per pCi				DR (pC		
Radionuclide	Radioactive Decay Constant 1/day	Conversion Factor mrem/uCi ingested	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario
Ge-68	2.40e-03	1.10e+00	8.03e-04	5.35e-04	4.05e-04	1.77e-04	6.23e+05	9.35e+05	1.23e+06	2.82e+06
Se-75	5.80e-03	1.40e+01	1.02e-02	4.25e-03	3.42e-03	1.78e-03	4.90e+04	1.18e+05	1.46e+05	2.81e+05
Rb-86	3.70e-02	9.40e+00	6.86e-03	5.08e-04	4.83e-04	4.01e-04	7.29e+04	9.84e+05	1.04e+06	1.25e+06
Sr-89	1.40e-02	9.30e+00	6.79e-03	1.32e-03	1.17e-03	7.78e-04	7.36e+04	3.79e+05	4.27e+05	6.43e+05
Sr-90	6.60e-05	1.40e+02	1.02e-01	1.01e-01	7.29e-02	2.74e-02	4.90e+03	4.95e+03	6.86e+03	1.82e+04
Y-90	2.60e-01	1.10e+01	8.03e-03	8.46e-05	8.40e-05	8.15e-05	6.23e+04	5.91e+06	5.95e+06	6.14e+06
Y-91	1.20e-02	9.50e+00	6.94e-03	1.56e-03	1.36e-03	8.67e-04	7.20e+04	3.21e+05	3.68e+05	5.77e+05
Zr-93	1.20e-03	1.70e+00	1.24e-03	1.00e-03	7.43e-04	3.01e-04	4.03e+05	5.00e+05	6.73e+05	1.66e+06
Zr-95	1.10e-02	4.70e+00	3.43e-03	8.39e-04	7.22e-04	4.50e-04	1.46e+05	5.96e+05	6.93e+05	1.11e+06
Nb-94	9.40e-08	7.10e+00	5.18e-03	5.18e-03	3.74e-03	1.40e-03	9.65e+04	9.65e+04	1.34e+05	3.57e+05
Nb-95	2.00e-02	4.70e+00	3.43e-03	4.70e-04	4.29e-04	3.14e-04	1.46e+05	1.06e+06	1.17e+06	1.59e+06
Mo-99	2.50e-01	3.00e+00	2.19e-03	2.40e-05	2.38e-05	2.31e-05	2.28e+05	2.08e+07	2.10e+07	2.16e+07
Tc-99	9.00e-09	1.50e+00	1.10e-03	1.09e-03	7.90e-04	2.95e-04	4.55e+05	4.59e+05	6.33e+05	1.69e+06
Ru-103	3.60e-02	3.00e+00	2.19e-03	1.67e-04	1.58e-04	1.31e-04	2.28e+05	2.99e+06	3.16e+06	3.82e+06
Ru/Rh-106	1.90e-03	2.70e+01	1.97e-02	1.42e-02	1.07e-02	4.51e-03	2.54e+04	3.52e+04	4.67e+04	1.11e+05
Ag-110m	2.80e-03	1.10e+01	8.03e-03	5.03e-03	3.84e-03	1.72e-03	6.23e+04	9.94e+04	1.30e+05	2.91e+05
Cd-109	1.50e-03	1.30e+01	9.49e-03	7.31e-03	5.44e-03	2.25e-03	5.27e+04	6.84e+04	9.19e+04	2.22e+05
Cd-113m	1.40e-04	1.60e+02	1.17e-01	1.14e-01	8.24e-02	3.11e-02	4.27e+03	4.39e+03	6.07e+03	1.61e+04
In-114m	1.40e-02	1.70e+01	1.24e-02	2.41e-03	2.13e-03	1.42e-03	4.03e+04	2.07e+05	2.35e+05	3.52e+05

Table 4-2. DRLs Associated with a Total Effective Dose Equivalent of 0.5 rem Resulting from One Year of Ingestion (continued)

		Dose		Normalize mrem per pCi				DR (pC		
Radionuclide	Radioactive Decay Constant 1/day	Conversion Factor mrem/uCi ingested	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario
Sn-113	6.00e-03	3.10e+00	2.26e-03	9.18e-04	7.41e-04	3.89e-04	2.21e+05	5.45e+05	6.75e+05	1.29e+06
Sn-123	5.40e-03	8.40e+00	6.13e-03	2.68e-03	2.14e-03	1.09e-03	8.16e+04	1.87e+05	2.34e+05	4.59e+05
Sn-125	7.20e-02	1.20e+01	8.76e-03	3.33e-04	3.25e-04	2.93e-04	5.71e+04	1.50e+06	1.54e+06	1.71e+06
Sn-126	1.80e-03	1.90e+01	1.39e-02	1.02e-02	7.61e-03	3.20e-03	3.60e+04	4.90e+04	6.57e+04	1.56e+05
Sb-124	1.20e-02	9.80e+00	7.15e-03	1.61e-03	1.40e-03	8.95e-04	6.99e+04	3.11e+05	3.57e+05	5.59e+05
Sb-126	5.60e-02	1.00e+01	7.30e-03	3.57e-04	3.45e-04	3.03e-04	6.85e+04	1.40e+06	1.45e+06	1.65e+06
Sb-127	1.80e-01	6.70e+00	4.89e-03	7.44e-05	7.37e-05	7.06e-05	1.02e+05	6.72e+06	6.78e+06	7.08e+06
Te-127	6.40e-03	8.30e+00	6.06e-03	2.34e-03	1.90e-03	1.02e-03	8.25e+04	2.14e+05	2.63e+05	4.90e+05
Te-129	2.40e-01	2.00e-01	1.46e-04	1.67e-06	1.65e-06	1.60e-06	3.42e+06	2.99e+08	3.03e+08	3.13e+08
Te-129m	2.10e-02	1.10e+01	8.03e-03	1.05e-03	9.60e-04	7.12e-04	6.23e+04	4.76e+05	5.21e+05	7.02e+05
Te-131m	5.50e-01	9.10e+00	6.64e-03	3.31e-05	3.30e-05	3.25e-05	7.53e+04	1.51e+07	1.52e+07	1.54e+07
Te/I-132	2.10e-01	9.40e+00	6.86e-03	8.95e-05	8.87e-05	8.55e-05	7.29e+04	5.59e+06	5.64e+06	5.85e+06
I-125	1.20e-02	3.80e+01	2.77e-02	6.25e-03	5.43e-03	3.47e-03	1.81e+04	8.00e+04	9.21e+04	1.44e+05
I-129	1.00e-08	2.80e+01	2.04e-02	2.04e-02	1.47e-02	5.50e-03	2.45e+04	2.45e+04	3.40e+04	9.09e+04
I-131	8.60e-02	5.30e+01	3.87e-02	1.23e-03	1.21e-03	1.11e-03	1.29e+04	4.07e+05	4.13e+05	4.50e+05
Cs-134	9.20e-04	7.30e+01	5.33e-02	4.53e-02	3.33e-02	1.32e-02	9.38e+03	1.10e+04	1.50e+04	3.79e+04
Cs-136	5.30e-02	1.10e+01	8.03e-03	4.15e-04	4.01e-04	3.50e-04	6.23e+04	1.20e+06	1.25e+06	1.43e+06
Cs/Ba137	6.30e-05	5.00e+01	3.65e-02	3.61e-02	2.61e-02	9.77e-03	1.37e+04	1.39e+04	1.92e+04	5.12e+04
Ba-133	1.80e-04	3.40e+00	2.48e-03	2.40e-03	1.74e-03	6.58e-04	2.02e+05	2.08e+05	2.87e+05	7.60e+05

Table 4-2. DRLs Associated with a Total Effective Dose Equivalent of 0.5 rem Resulting from One Year of Ingestion (continued)

		Dose		Normalize mrem per pCi			DRLs (pCi/L)			
Radionuclide	Radioactive Decay Constant 1/day	Conversion Factor mrem/uCi ingested	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario
Ba-140	5.40e-02	9.50e+00	6.94e-03	3.52e-04	3.40e-04	2.97e-04	7.20e+04	1.42e+06	1.47e+06	1.68e+06
La-140	4.10e-01	8.40e+00	6.13e-03	4.10e-05	4.08e-05	4.00e-05	8.16e+04	1.22e+07	1.23e+07	1.25e+07
Ce-141	2.10e-02	2.90e+00	2.12e-03	2.76e-04	2.53e-04	1.88e-04	2.36e+05	1.81e+06	1.98e+06	2.66e+06
Ce-143	5.00e-01	4.60e+00	3.36e-03	1.84e-05	1.83e-05	1.80e-05	1.49e+05	2.72e+07	2.73e+07	2.78e+07
Ce/Pr-144	2.40e-03	2.10e+01	1.53e-02	1.02e-02	7.73e-03	3.38e-03	3.27e+04	4.90e+04	6.47e+04	1.48e+05
Nd-147	6.30e-02	4.40e+00	3.21e-03	1.40e-04	1.36e-04	1.21e-04	1.56e+05	3.57e+06	3.68e+06	4.13e+06
Pm-145	1.10e-04	4.70e-01	3.43e-04	3.36e-04	2.43e-04	9.15e-05	1.46e+06	1.49e+06	2.06e+06	5.46e+06
Pm-147	7.20e-04	1.00e+00	7.30e-04	6.42e-04	4.70e-04	1.84e-04	6.85e+05	7.79e+05	1.06e+06	2.72e+06
Pm-149	3.10e-01	4.00e+00	2.92e-03	2.58e-05	2.56e-05	2.50e-05	1.71e+05	1.94e+07	1.95e+07	2.00e+07
Pm-151	5.90e-01	3.00e+00	2.19e-03	1.02e-05	1.01e-05	1.00e-05	2.28e+05	4.90e+07	4.95e+07	5.00e+07
Sm-151	2.10e-05	3.90e-01	2.85e-04	2.84e-04	2.05e-04	7.65e-05	1.75e+06	1.76e+06	2.44e+06	6.54e+06
Eu-152	1.00e-04	6.50e+00	4.75e-03	4.66e-03	3.37e-03	1.27e-03	1.05e+05	1.07e+05	1.48e+05	3.94e+05
Eu-154	2.20e-04	9.50e+00	6.94e-03	6.66e-03	4.83e-03	1.83e-03	7.20e+04	7.51e+04	1.04e+05	2.73e+05
Eu-155	3.80e-04	1.50e+00	1.10e-03	1.02e-03	7.43e-04	2.85e-04	4.55e+05	4.90e+05	6.73e+05	1.75e+06
Gd-153	2.90e-03	1.20e+00	8.76e-04	5.40e-04	4.13e-04	1.86e-04	5.71e+05	9.26e+05	1.21e+06	2.69e+06
Tb-160	9.60e-03	6.70e+00	4.89e-03	1.35e-03	1.15e-03	6.87e-04	1.02e+05	3.70e+05	4.35e+05	7.28e+05
Ho-166m	1.60e-06	8.10e+00	5.91e-03	5.91e-03	4.26e-03	1.59e-03	8.46e+04	8.46e+04	1.17e+05	3.14e+05
Tm-170	5.40e-03	5.30e+00	3.87e-03	1.69e-03	1.35e-03	6.90e-04	1.29e+05	2.96e+05	3.70e+05	7.25e+05
Yb-169	2.20e-02	3.00e+00	2.19e-03	2.73e-04	2.51e-04	1.88e-04	2.28e+05	1.83e+06	1.99e+06	2.66e+06

Table 4-2. DRLs Associated with a Total Effective Dose Equivalent of 0.5 rem Resulting from One Year of Ingestion (continued)

		Dose		Normalize mrem per pCi				DR (pC		
Radionuclide	Radioactive Decay Constant 1/day	Conversion Factor mrem/uCi ingested	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario
Hf-181	1.60e-02	4.70e+00	3.43e-03	5.86e-04	5.24e-04	3.63e-04	1.46e+05	8.53e+05	9.54e+05	1.38e+06
Ta-182	6.00e-03	6.50e+00	4.75e-03	1.92e-03	1.55e-03	8.15e-04	1.05e+05	2.60e+05	3.23e+05	6.14e+05
W-187	6.93e-01	2.80e+00	2.04e-03	8.08e-06	8.06e-06	7.97e-06	2.45e+05	6.19e+07	6.20e+07	6.27e+07
Ir-192	9.40e-03	5.70e+00	4.16e-03	1.17e-03	9.93e-04	5.90e-04	1.20e+05	4.27e+05	5.04e+05	8.47e+05
Au-198	2.60e-01	4.20e+00	3.07e-03	3.23e-05	3.21e-05	3.11e-05	1.63e+05	1.55e+07	1.56e+07	1.61e+07
Hg-203	1.50e-02	1.10e+01	8.03e-03	1.46e-03	1.30e-03	8.83e-04	6.23e+04	3.42e+05	3.85e+05	5.66e+05
Tl-204	5.00e-04	3.40e+00	2.48e-03	2.27e-03	1.65e-03	6.39e-04	2.02e+05	2.20e+05	3.03e+05	7.82e+05
Pb-210	1.00e-04	5.40e+03	3.94e+00	3.87e+00	2.80e+00	1.05e+00	1.27e+02	1.29e+02	1.79e+02	4.76e+02
Bi-207	1.00e-04	5.50e+00	4.02e-03	3.94e-03	2.85e-03	1.07e-03	1.24e+05	1.27e+05	1.75e+05	4.67e+05
Bi-210	1.40e-01	6.40e+00	4.67e-03	9.14e-05	9.02e-05	8.54e-05	1.07e+05	5.47e+06	5.54e+06	5.85e+06
Po-210	5.00e-03	1.90e+03	1.39e+00	6.37e-01	5.06e-01	2.54e-01	3.60e+02	7.85e+02	9.88e+02	1.97e+03
Ra-226	1.20e-06	1.30e+03	9.49e-01	9.49e-01	6.84e-01	2.56e-01	5.27e+02	5.27e+02	7.31e+02	1.95e+03
Ac-227	1.00e-04	1.40e+04	1.02e+01	1.00e+01	7.25e+00	2.73e+00	4.90e+01	5.00e+01	6.90e+01	1.83e+02
Th-227	3.70e-02	3.80e+01	2.77e-02	2.05e-03	1.95e-03	1.62e-03	1.81e+04	2.44e+05	2.56e+05	3.09e+05
Th-228	1.00e-03	4.00e+02	2.92e-01	2.45e-01	1.80e-01	7.20e-02	1.71e+03	2.04e+03	2.78e+03	6.94e+03
Th-230	2.50e-08	5.50e+02	4.02e-01	4.01e-01	2.90e-01	1.08e-01	1.24e+03	1.25e+03	1.72e+03	4.63e+03
Th-232	1.00e-08	2.70e+03	1.97e+00	1.97e+00	1.42e+00	5.31e-01	2.54e+02	2.54e+02	3.52e+02	9.42e+02
Pa-231	1.00e-08	1.10e+04	8.03e+00	8.03e+00	5.79e+00	2.16e+00	6.23e+01	6.23e+01	8.64e+01	2.31e+02
U-232	2.60e-05	1.30e+03	9.49e-01	9.45e-01	6.82e-01	2.55e-01	5.27e+02	5.29e+02	7.33e+02	1.96e+03

Table 4-2. DRLs Associated with a Total Effective Dose Equivalent of 0.5 rem Resulting from One Year of Ingestion (continued)

		Dose		Normalize mrem per pCi				DRLs (pCi/L)			
Radionuclide	Radioactive Decay Constant 1/day	Conversion Factor mrem/uCi ingested	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario	
U-233	1.00e-08	2.90e+02	2.12e-01	2.12e-01	1.53e-01	5.70e-02	2.36e+03	2.36e+03	3.27e+03	8.77e+03	
U-234	1.00e-08	2.80e+02	2.04e-01	2.04e-01	1.47e-01	5.50e-02	2.45e+03	2.45e+03	3.40e+03	9.09e+03	
U-235	1.00e-08	2.70e+02	1.97e-01	1.97e-01	1.42e-01	5.31e-02	2.54e+03	2.54e+03	3.52e+03	9.42e+03	
U-238	1.00e-08	2.50e+02	1.83e-01	1.82e-01	1.32e-01	4.91e-02	2.73e+03	2.75e+03	3.79e+03	1.02e+04	
Np-237	1.00e-08	4.40e+03	3.21e+00	3.21e+00	2.32e+00	8.65e-01	1.56e+02	1.56e+02	2.16e+02	5.78e+02	
Np-239	2.90e-01	3.30e+00	2.41e-03	2.28e-05	2.26e-05	2.20e-05	2.07e+05	2.19e+07	2.21e+07	2.27e+07	
Pu-236	7.00e-04	1.20e+03	8.76e-01	7.73e-01	5.66e-01	2.22e-01	5.71e+02	6.47e+02	8.83e+02	2.25e+03	
Pu-238	2.20e-05	3.20e+03	2.34e+00	2.33e+00	1.68e+00	6.28e-01	2.14e+02	2.15e+02	2.98e+02	7.96e+02	
Pu-239	1.00e-08	3.50e+03	2.56e+00	2.55e+00	1.84e+00	6.88e-01	1.95e+02	1.96e+02	2.72e+02	7.27e+02	
Pu-240	2.90e-07	3.50e+03	2.56e+00	2.55e+00	1.84e+00	6.88e-01	1.95e+02	1.96e+02	2.72e+02	7.27e+02	
Pu-241	1.30e-04	6.80e+01	4.96e-02	4.85e-02	3.51e-02	1.32e-02	1.01e+04	1.03e+04	1.42e+04	3.79e+04	
Pu-242	1.00e-08	3.40e+03	2.48e+00	2.48e+00	1.79e+00	6.68e-01	2.02e+02	2.02e+02	2.79e+02	7.49e+02	
Am-241	4.40e-06	3.60e+03	2.63e+00	2.63e+00	1.89e+00	7.07e-01	1.90e+02	1.90e+02	2.65e+02	7.07e+02	
Am-242m	1.20e-05	3.50e+03	2.56e+00	2.55e+00	1.84e+00	6.87e-01	1.95e+02	1.96e+02	2.72e+02	7.28e+02	
Am-243	2.60e-07	3.60e+03	2.63e+00	2.63e+00	1.90e+00	7.08e-01	1.90e+02	1.90e+02	2.63e+02	7.06e+02	
Cm-242	4.30e-03	1.10e+02	8.03e-02	4.05e-02	3.18e-02	1.54e-02	6.23e+03	1.23e+04	1.57e+04	3.25e+04	
Cm-243	6.67e-05	2.50e+03	1.83e+00	1.80e+00	1.30e+00	4.88e-01	2.73e+02	2.78e+02	3.85e+02	1.02e+03	
Cm-244	1.00e-04	2.00e+03	1.46e+00	1.43e+00	1.04e+00	3.90e-01	3.42e+02	3.50e+02	4.81e+02	1.28e+03	
Cm-245	2.20e-07	3.70e+03	2.70e+00	2.70e+00	1.95e+00	7.27e-01	1.85e+02	1.85e+02	2.56e+02	6.88e+02	

Table 4-2. DRLs Associated with a Total Effective Dose Equivalent of 0.5 rem Resulting from One Year of Ingestion (continued)

		Dose		Normalize mrem per pCi				DR (pC		
Radionuclide	Radioactive Decay Constant 1/day	Conversion Factor mrem/uCi ingested	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario	Without Radioactive Decay	With Radioactive Decay Only	Reservoir Scenario	River Scenario
Cm-246	4.00e-07	3.70e+03	2.70e+00	2.70e+00	1.95e+00	7.27e-01	1.85e+02	1.85e+02	2.56e+02	6.88e+02
Cf-252	7.20e-04	1.10e+03	8.03e-01	7.06e-01	5.17e-01	2.03e-01	6.23e+02	7.08e+02	9.67e+02	2.46e+03

# APPENDIX G

Basis for the Water PAG

Draft 3/21/2003

# Contents

G.1	Assumptions and Selection Criteria	G-1
G.2	Potential Pathways and Doses	G-2
G.3	Potential Longer Term Protective Actions	G-4
G.4	Candidate Exposures	G-4
G.5	Analysis Results	G-4
G.6	Establishing Derived Intervention Levels	G-10
G.7	Comparison to ICRP 72 Dose Conversion Factors	G-12
G.8	Comparison to Federal Guidance Report 13	G-16
Refere	ences	G-21

Draft 3/21/2003

#### Basis for the Water PAG

Under the Federal Emergency Management Agency's (FEMA) regulations governing radiological emergency planning and preparedness, the Environmental Protection Agency (EPA) is responsible for: (1) establishing Protective Action Guides (PAGs); (2) preparing guidance on implementing PAGs; and (3) developing and presenting training programs for state and local officials on the PAGs. In its effort to develop a Water PAG, EPA performed several studies that: (1) identified the significant exposure pathways associated with the use of water; (2) estimated the cost of providing alternative sources of drinking water; and (3) estimated the cost-benefit relationship of various dose levels that could provide longer term protection for drinking water supplies.

# **G.1** Assumptions and Selection Criteria

In developing the Water PAG, EPA assumed that protective actions for drinking water supplies would likely be taken during the intermediate and recovery phases of a nuclear incident (see Chapter 3 and Table 3-1). We made this assumption because it will take some time after the radioactive plume passes to determine the full extent of any contamination to surface water bodies. In addition, it is unlikely that emergency response personnel will have the results from radiation measurements of water supplies until well after the plume has passed. Chapter 3 of this manual provides a detailed discussion of a variety of protective actions that can be taken during the intermediate phase of a nuclear incident. EPA has set the water protective action guide at a dose level of 0.5 rem total effective dose equivalent to ensure consistency with the recommendations given in Chapter 3. We consider that this dose level will provide an acceptable level of safety to an affected community for the year following a nuclear incident. (Of course, this risk level is expected to decline during and after the first year.)

EPA also looked at guidance issued by other organizations, as well as by other parts of the Agency in developing the Water PAG. Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), EPA has the responsibility for the clean up of sites contaminated with radionuclides or other hazardous materials. In the past, the Agency has used a risk level of 1 in 10,000 (1 x 10<sup>-1</sup>) to guide these clean up activities. A one-year exposure of 0.5 rem produces an individual lifetime cancer incidence risk of slightly above 10<sup>-4</sup>. Thus, the Water PAG dose level is consistent with clean up criteria used by EPA under CERCLA. Similarly, the International Commission on Radiological Protection (ICRP) recommends intervention efforts following a nuclear emergency at a dose level of 0.5 rem. In particular, the ICRP recommends controlling exposures from food above 5 milliSievert. (Five milliSievert is equal to 0.5 rem.) This intervention level, and the reasons for it, are discussed in more detail in Appendix H of this manual.

Draft G-1 3/21/2003

The ICRP also suggests that agencies optimize the net benefit of an intervention strategy based on their knowledge of local situations, as well as their assumptions about the monetary value to a particular dose level. EPA recognizes this as an acceptable strategy. Therefore, after a particular situation stabilizes and becomes more clearly defined, local authorities may wish to modify the level of drinking water exposure they consider to be acceptable based upon a desire to implement optimized longer term dose reduction strategies. In other words, the dose level associated with the drinking water pathway may be controlled to levels below 0.5 rem, depending on the characteristics of an individual community and a site-specific cost-benefit analysis.

In the following sections, we provide a cost-benefit analysis for varying levels of protection. This analysis will help guide the development of a strategy to provide long term protection of the drinking water servicing a community. EPA's risk analysis shows that individuals can receive a significant radiation dose from contaminated drinking water after a nuclear incident has occurred. However, most of the seven protective actions described in this appendix are cost-effective, in the short term (less than one year), at all levels of protection, including EPA's current drinking water standard of 4 millirem/year (mrem/yr). For time periods of one year or longer, drinking water can be cost-effectively protected to below 50 mrem/yr by treating the contaminated water or by activating existing connections to neighboring systems.

# **G.2** Potential Pathways and Doses

1 2

Because there are many uses for water, it was necessary to evaluate the need for: (1) restricting uses of water other than drinking, and (2) developing different response levels for other uses of water. EPA identified 12 subsidiary uses of drinking water and 26 exposure pathways, e.g., inhalation of radioactivity while showering, for evaluation.

A radiation exposure pathway model was developed for each exposure pathway to estimate the annual dose to an individual performing the identified activity. Depending on the exposure pathway, the estimated dose was identified as being attributable to either occupational or non-occupational activities. The scenarios analyzed 27 radionuclides generally associated with uranium fuel cycle activities. The ratio of the dose for the subsidiary exposure pathway to the dose for the drinking water pathway for each radionuclide was calculated. An average dose ratio was then calculated for those radionuclides that could provide a significant dose for each exposure pathway. This average ratio was taken as a representative measure of the significance of the pathway for dose control purposes. Table G-1 lists the water uses, exposure pathways, and their associated average ratios.

Table G-1 shows that, with the exception of the first three pathways (water treatment service, power spray cleaning, and vegetable garden irrigation), the doses from the other uses of water are much lower than the doses from drinking the water. However, the doses from the first three pathways can be controlled without the use of pathway-specific dose restrictions. In the event of an incident that releases enough radioactive material to cause these three pathways to be significant, protective actions that prohibit or severely limit these activities will probably be

Table G-1 Comparison of Doses from Alternative Water Pathways and Scenarios Relative to Drinking Water (see Reference 5)

Alternative Water Use Scenario	Exposure Pathway	Ratio Relative to Drinking Water
Water treatment service man	External	14
Power spray cleaning	Inhalation	2.1
Vegetable garden irrigation	Ingestion	1.8
Commercial laundry	Inhalation	0.4
Commercial car wash	Inhalation	0.3
Household water treatment	External	0.3
Vegetable garden irrigation	External	0.2
Lawn irrigation	External	0.2
Laundry-contaminated clothes	Skin dose	0.1
Bathing-shower	Inhalation	0.09
Fire fighting	Inhalation	0.07
Post fire fighting	External	0.05
Swimming	External	0.04
Swimming	Ingestion	0.02
Bathing-tub	Immersion	0.02
Washing floors	External	0.02
Dish washing-automatic	Inhalation	0.01
Pool filter replacement	External	0.005
Garden irrigation	Inhalation	0.004
Dish washing-manual	Ingestion	0.004
Lawn irrigation	Inhalation	0.004
Food rinsing	Ingestion	0.002
Dish washing-manual	Skin dose	0.002
Bathing	Skin dose	0.0002
Car washing	External	0.00001

implemented. Therefore, our cost-benefit analysis was limited to the consideration of the ingestion of contaminated water, identifying alternative sources of drinking water, estimating the cost associated with supplying that water to the general population, and estimating the cost per person-rem avoided for varying levels of exposure.

# **G.3** Potential Longer Term Protective Actions

1 2 3

4

5

6 7

8

9

10

11

16

17

18 19

20

21 22

23

24

2526

27

28

29

30

31

32 33 EPA determined that local public officials have at least the following seven options for dealing with contaminated drinking water supplies:

- 1. Wait for flow-by
  - 2. Ration clean water supplies;
  - 3. Treat contaminated water;
- 4. Activate existing connections to neighboring systems;
  - 5. Establish pipeline connections to closest source/system;
- 6. Import water in tanker trucks; or
  - 7. Import bottled water.

These actions may be taken alone or in conjunction with one another, depending on the nature of

- the incident and the characteristics of the local water system. The appropriate action will depend
- on the feasibility, timeliness, and/or cost of satisfying the health objectives of the action. An
- analysis of each option is provided in Reference 4.

#### **G.4** Candidate Dose Levels

For each protective action listed above, the Agency conducted a cost-benefit analysis for the following candidate dose levels: 500 mrem, 250 mrem, 200 mrem, 100 mrem, 50 mrem, 20 mrem, 10 mrem, and 4 mrem. The 500 mrem value was selected because it is the recommended water protective action guide. The 250 mrem value was selected because it approximates the lifetime dose from consuming water at the drinking water standard of 4 mrem/year. The value of 100 mrem was selected in consideration of its regulatory precedent as set forth in 10 CFR Part 20 and Federal Guidance Report No. 11. The 4 mrem value was selected because 4 mrem/year has been established as the drinking water standard in 40 CFR Part 141. The 50 mrem, 20 mrem, and 10 mrem values were selected as reasonable intermediate values between the 100 and 4 mrem values. In addition, the analysis of the costs and benefits considered intervention durations of one month, three months, and one year.

## **G.5** Analysis Results

The results of EPA's cost analysis show that the costs of providing uncontaminated drinking water via the different options varies greatly. Following is an option-by-option summary of these results. The results of this analysis are summarized in Table G-2. EPA used these cost values to estimate the cost-benefit ratio, in terms of dollars-per-rem avoided, for various dose levels.

Option	Cost-per-Liter			
Wait for Flow-By	\$0.00025			
Ration Clean Water Supplies	\$0.06 to \$0.27			
Treat Contaminated Water	\$0.00011 to \$0.003			
Activate Existing Connections	\$0.00016 to \$0.00025			
Build Pipeline Connections	\$0.02 to \$0.04			
Import Water in Tanker Trucks	\$0.09 to \$0.10			
Import Bottled Water	\$0.21 to \$0.22			

#### Option 1: Wait for Flow-By

If the contaminated water is in the form of a plume moving down a river, the relevant source intake valve may be closed, allowing the plume to pass and dilution to occur. While the intake valve is closed, the system may utilize existing water storage capacity; large systems usually possess 12 to 24 hours of water storage capacity. If the intake valve must be closed for a longer period of time, the contaminated water may be treated while the stored supplies are being used, provided that the treatment technology is either in place or readily available.

The cost of utilizing stored water while waiting for a plume of contaminated water to pass is extremely low. If clean water is blended into the supply system to reduce the concentration of radionuclides in the contaminated water, then the cost of the clean water that is purchased must be considered. Depending on the characteristics of the water, other costs, such as disinfection, may be incurred. However, the cost still remains relatively low, about \$1.00 per 1,000 gallons or \$0.00025 per liter of water.

## Option 2: Ration Clean Water Supplies

If water reserves are limited, but can provide each individual with one liter of water per day until either: (1) the contaminated plume has passed; (2) the contaminated water has been treated; or (3) the water supply system has returned to normal operating conditions, then the water reserves may have to be rationed. Use of rationing requires that the contamination be isolated from the system, or in a single area of the system, and that efficient methods for rationing exist. Similarly, if only limited water treatment capabilities exist, then rationing may be required.

Since the rationing of water can occur in conjunction with other water supply or treatment options, it is difficult to estimate the cost of rationing. The cost of rationing was estimated for two options. The first option involves bottling water at a central location and then delivering the bottles to distribution centers located in the affected community. The second option involves transporting the water to distribution centers through fire hoses connected to hydrants located in the uncontaminated portion of the water supply system. The costs for this option range from \$0.06 to \$0.09 per liter, while the cost for delivery by bottles is estimated to be \$0.27 per liter of water.

## Option 3: Treat Contaminated Water

Contamination of drinking water by man-made radionuclides may be reduced or eliminated through the use of various treatment technologies. According to a 1986 survey of community water supply systems, fewer than 10 percent of all water systems treat specifically for radionuclides. However, typical technologies used to treat water for other contaminants, such as coagulation/filtration, ion exchange, lime softening, and reverse osmosis can reduce the concentration of radioactivity. The removal efficiency depends on the radionuclide and the type of treatment. For example, ion exchange can remove up to 99 percent of the strontium-89, strontium-90, cesium-134, cesium-137, iodine-131, and cobalt-60 from a contaminated system. Reverse osmosis provides the highest removal efficiencies for alpha emitters such as plutonium-239.

The cost-per-gallon of water treated depends on such factors as capital costs, operating and maintenance costs, type of treatment system utilized, duration of incident, size of water supply system, and location of treatment system (e.g., central supply system treatment or point-of-use treatment). The estimated cost ranges from \$0.00011 to \$0.003 per liter of water.

# Option 4: Activate Existing Connections to Neighboring Systems

If the water supply system is part of a larger, regional supply system, existing connections to a neighboring system may be activated. Special care must be taken to ensure that the "clean" system does not become contaminated from water backflow. Most large water systems can establish connections with other large systems for emergency purposes. However, unlike members of the power utility industry, who balance their loads by routinely buying and selling electricity, water supply systems do not routinely purchase water from one another. Smaller water supply systems, serving between 10,000 and 75,000 people, are not normally connected to neighboring systems. System-to-system connections are also not feasible in sparsely populated or rural areas when such systems are great distances apart. However, for some smaller systems, regionalization may be attractive. This involves the connection of smaller systems to larger systems, thus forming a regional water supply organization.

Because of the emergency, a lending system should be expected to charge the borrowing system the lowest possible rate. Depending on the characteristics of the systems, the lender may only charge for connection, pumping, and electric costs. The cost of this option is estimated to range from \$0.00016 to \$0.00025 per liter of water.

## Option 5: Establish Pipeline Connections to Closest Sources/Systems

A routine means of providing clean water is to run a pipeline from a clean system to various distribution centers located throughout the affected community. For example, when water mains must be repaired or cleaned of debris, community water needs have been met through the assembly of temporary pipes and hoses. This is a relatively simple procedure, requiring very little construction and technical expertise. For medium- to long-term emergencies, the construction of a temporary pipeline may be cost-effective. PVC pipe, fire hoses, and steel pipe have been used to provide emergency drinking water for periods of up to

two months when service has been disrupted by earthquakes, drought, or bacterial contamination.

To estimate the cost of transmitting water via such temporary pipelines, it can be assumed that a 10-mile pipeline would cost about \$0.02 per liter, while a 25-mile pipeline would cost about \$0.04 per liter of water.

# Option 6: Import Water in Tanker Trucks

If an uncontaminated source of water is close to the affected area, it may be more efficient to transport water from that source by truck, rail, or barge to distribution centers located throughout the community. The most significant obstacles to the use of this option are the cleanliness and availability of transport vehicles. For example, Florida law states that tanker trucks may be used to transport water only in emergency situations due to concerns regarding tank cleanliness and water quality. According to officials at the U.S. Army Corps of Engineers and the Federal Emergency Management Agency, the most useful and efficient methods for transporting emergency water supplies are trucks and tank trailers (when they are approved for that use).

The cost of water transported by tanker trucks depends on a number of factors, which include the length of the trip, tanker capacity, labor rates, and distribution time. Assuming that each tanker will make a round trip of 100 miles and the water is then transferred to smaller tanker trucks (water buffaloes) for distribution throughout the affected community, the estimated cost-per-liter of water is \$0.09 to \$0.10.

# Option 7: Import Bottled Water

Bottled water may also be imported into the affected community. The water may come from a nearby water supply system or from a local spring water bottling company. This option may be cost-effective during an emergency if water is needed quickly and if the length of the emergency does not merit long-term action, such as the construction of a temporary pipeline. This option has been used in numerous emergency situations, including Hurricane Andrew.

The cost of importing bottled water is similar to that of importation of water by tanker trucks. Assuming that: (1) each flatbed truck makes a 100-mile round trip and is capable of carrying 4,536 one-gallon bottles of water and (2) the bottles are distributed to the public at various distribution centers throughout the affected community, the cost of this option is estimated to be \$0.21 to \$0.22 per liter of water.

Any protective action taken in response to a nuclear incident should result in a net societal benefit when the cost of the intervention is compared to the health detriment averted. The selection of the Water PAG was based in part on estimates of the relative benefit to the society, in terms of dollars-per-rem avoided, so that the different scenario options may be compared against each other. The measure used is simply the total dollars expended to avoid the projected exposures divided by the doses that would have been received during the intervention period.

- 1 The following costs-per-liter were used for the analysis:
- A. Water treatment (small system) 0.30 cents,
- B. Water treatment (large system) 0.01 cents,
- 4 C. Activate existing connection 0.025 cents,
- D. Run 10-mile pipeline to closest source 0.5, 1.1, and 2 cents for 1 year, 3 months, and 1 month, respectively,
  - E. Run 25-mile pipeline to closest source 0.9, 2.5, and 7 cents for 1 year, 3 months, and 1 month, respectively
  - F. Import water by tanker 10 cents, and
- 10 G. Import bottled water 22 cents.

Tables G-3, G-4, and G-5 present the results of what is essentially an As Low As Reasonably Achievable (ALARA) analysis. The tables present the cost-benefit ratios [Note, CERCLA remedial decisions made using cost-effectiveness, not cost-benefit, analysis. I am not familiar with any removal guidance based on cost-benefit analysis] calculated for various dose levels and water intervention options for one-month, three-month, and one-year intervention periods. The entries in the tables represent the dollars/rem avoided assuming that the total dose avoided per person during the specified intervention period is that listed as the dose level. Longer intervention periods would correspondingly increase the cost per person-rem averted, while shorter intervention periods would decrease the cost per person-rem avoided. It is assumed that each individual is provided one liter of drinking water per day during the intervention period.

Using the criteria in EPA's "Guidelines for Performing Regulatory Impact Analysis," an acceptable cost-benefit range of less than \$3,500 per person-rem averted can be established (see Reference 6). This assumes the value of a life saved ranges less than \$7,000,000 and the risk coefficient is  $5 \times 10^{-4}$  fatal cancers per person-rem. With the exception of importing water for the 20 mrem, 10 mrem, and 4 mrem levels during the longer intervention time periods, all the cost-benefit ratios fall within the Agency's acceptable range. Those ratios that fall within the cost-benefit range of less than \$3,500 have been identified (see shaded-in area) in the tables.

Local public officials can use these results to guide their selection of longer term dose reduction strategies for contaminated water supplies. For time periods of three months or less, almost all intervention strategies are cost-effective at a protection level as low as 4 mrem. However, if longer term protection is desired, only treating the water or connecting to an uncontaminated system can provide this level of protection. If these two options are not feasible, local officials may need to accept an intervention strategy that results in higher dose levels.

Draft G-8 3/21/2003

Table G-3 Cost-Benefit Ratios for One-Month Intervention Duration (\$/rem avoided)

Dose Level			Int	ervention Opt	ion		
(mrem)	A	В	C	D	E	F	G
500	<1	<1	<1	1	4	6	13
250	<1	<1	<1	2	8	12	26
100	1	<1	<1	6	21	30	66
50	2	<1	<1	12	42	60	132
20	5	<1	<1	30	105	150	330
10	9	<1	1	60	210	300	660
4	23	1	2	150	525	750	1650

Table G-4 Cost-Benefit Ratios for Three-Month Intervention Duration (\$/rem avoided)

Dose Level	Intervention Option														
(mrem)	A	В	C	D	E	F	G								
500	<1	<1	<1	2	5	18	40								
250	1	<1	<1	4	9	36	80								
100	3	<1	<1	10	23	90	200								
50	5	<1	<1	20	45	180	400								
20	14	<1	1	50	113	450	1000								
10	27	<1	2	99	225	900	2000								
4	68	2	6	248	563	2250	4950								

Table G-5 Cost-Benefit Ratios for a One-Year Intervention Duration (\$/rem avoided)

Dose Level	Intervention Option														
(mrem)	A	В	C	D	E	F	G								
500	2	<1	<1	4	7	73	161								
250	4	<1	<1	7	13	146	321								
100	11	<1	1	18	33	365	803								
50	22	<1	2	37	66	730	1606								
20	55	2	5	91	164	1825	4015								
10	110	4	9	183	329	3650	8030								
4	274	9	23	456	821	9125	20075								

## **G.6** Establishing Derived Intervention Levels

22.

The final step in developing the Water PAG was to calculate derived response levels (DRLs). These levels will allow emergency response personnel to determine whether the radionuclide concentrations in water are likely to exceed the Water PAG of 0.5 rem. DRLs were derived for a total of 27 radionuclides. The Agency considered a number of options for selecting the list of radionuclides requiring DRLs. These included: (1) the approach taken by the Food and Drug Administration (FDA) for the interdiction of human food and animal feed that followed the general philosophy of the international agencies (see Reference 7); (2) the development of a list based on the types of incidents of concern; (3) using a complete listing of virtually all radionuclides; (4) using the list developed for the plume pathway DRLs (see Reference 2); and (5) presenting guidance on developing site-specific DRLs without providing specific values. Each approach has its advantages and limitations.

Option 1, the FDA selection of radionuclides for consideration, is based on experience with the Chernobyl accident, where iodine-131, cesium-134, and cesium-137 were principal contaminants, and on potential releases of strontium-90, plutonium-239, and americium-241 from nuclear fuel reprocessing and waste management activities. In addition, nuclear weapons accidents involving dispersion without nuclear detonation produce further concern for plutonium-239. Also, accidents involving radioisotope thermoelectric generators and radioisotope heater units used in space vehicles require guidelines for plutonium-238. Concentrations for strontium-90 and iodine-131 were listed individually, while the groups cesium-134/cesium-137 and plutonium-238/plutonium-239/americium-241 were considered as single concentrations.

The FDA further states that if contamination events involving radionuclides other than those mentioned contributed predominantly large concentrations, these would be evaluated by the responsible agency on a case-by-case basis to determine if the concentrations exceeded the PAG. In the case of potable water concentrations, this would mean EPA must be involved in the evaluation to determine if additional or special purpose concentrations are considered necessary.

This approach has the advantage of simplicity in that it would apply to most accidents, however it would require additional technical evaluations where unlisted radionuclides were dispersed. More unlikely events, such as acts of sabotage, conceivably could involve other radionuclides but, in general, the FDA selection presents the most restrictive concentrations and can be applied to other radionuclides.

A second option would be to select a group of radionuclides associated with the nuclear fuel cycle, including neutron activation products. This selection would consider radioactive half-lives, dose conversion factors, fission yields, and the possibilities for significant neutron activation products. An example would be the selection of all radionuclides with half lives greater than eight days, dose conversion factors greater than 10 mrem/ $\mu$ Ci, fission yields greater than 0.1 percent, thermal neutron capture cross sections of greater than 0.1 barn, and target material of greater than one isotopic percent. Table G-6 presents a list of radionuclides based on these criteria.

P-32	Zr-93	Ce-141 & Ce-144
Fe-59	Ru-106	Pr-143
Co-60	Cd-115m	Nd-147
Zn-65	Sn-311	Pm-147-148m
Se-75	Te-127m &Te-129m	Pu-238 & Pu-239
Rb-86	I-131	Am-241
Sr-89 & Sr-90	Cs-134 & Cs-137	Cm-242 & Cm-244
Y-91	Ba-140	

The advantage of this listing is the wider variety of radionuclide guidance concentrations available without additional calculation and evaluation. However, this may imply the need for greater analytical requirements than for the shorter list of the first option, which may not be justified in most events.

The third option would be to adopt the list of all longer-lived radionuclides. These radionuclides have half-lives of sufficient length to allow the possibility of water contamination that could reach the population assuming there are not holding times for the water. This option would also assume that any degree of radioactivity could produce dose equivalents that could exceed PAG levels. This list would be similar to the list presented in Federal Guidance Report No. 11, which contains several hundred radionuclides.

The fourth option, the list of radionuclides contained in Table 5-3 in Reference 2, was reduced by eliminating those radionuclides with a half-life of less than one day. Table 5-3 in Reference 2 presents the DRLs for the air exposure pathway. As such, even relatively short-lived radionuclides are of concern due to the short time from a release to an exposure via the airborne pathways. For the drinking water pathways, there is substantial delay between the contaminating event and exposure. For example, the typical turnover rate of a reservoir is one year. Accordingly, the short-lived radionuclides were deleted from this list. This option was selected for the Water PAG because it includes a comprehensive list of potentially important radionuclides and is consistent with the approach used in developing the implementation guidance for the air exposure PAGs.

The fifth option, which provides guidance on developing DRLs without providing specific values, was rejected because it would be of limited use to emergency response personnel during an accident. In addition, emergency response personnel always have the option to derive site- and event-specific response levels.

## G.7 Discussion Concerning the New Age-Dependent Dosimetry

EPA derived the DRLs in Chapter 4 using the Federal Guidance Report No. 11 dose coefficients. These dose coefficients were based upon the International Commission on Radiological Protection (ICRP) Publication 30 (1979) which established dosimetric models and biokinetic data for adult workers (Reference 9). At that time there were no recommended models and data for members of the general public which include all age groups. Between 1989 and 1996 the ICRP published new age-dependent dose coefficients for members of the general public (ICRP Publications 56, 67, 69 - References 10, 11, 12). The ICRP used updated age-dependent metabolic models and radionuclide-specific biokinetic data to calculate the new dose coefficients. ICRP summarized these coefficients in ICRP Publication 72 (Reference 13).

The ICRP based their age-dependent dose coefficients on a unit intake of radionuclides at six different ages (3 months, 1 year, 5 years, 10 years, 15 years, and adult). The ICRP established age-dependent reference values encompassing both sexes for organ mass and body size, absorption, retention and clearance. In almost every case the resulting dose coefficients are the highest for the youngest age group (< 1 year). This is due to increased radionuclide intake and smaller organ mass during the first year of life. For many of the radionuclides that are important during the first year of exposure following an accident, the dose coefficients for the youngest age group can be an order of magnitude or more greater than the coefficients for adults.

People involved in protecting members of the general public following a nuclear incident may wish to use the age dependent dose coefficients in ICRP Publication 72. These coefficients will allow those responsible for radiation protection to evaluate more accurately the impacts of exposure to various age groups in the effected population.

## **G.8** Comparison to Federal Guidance Report 13

The EPA compared the approach taken in this manual to the newer approach in Federal Guidance Report No.13 to determine if our recommended generic DRLs in Chapter 4 were health protective. The EPA recently finalized Federal Guidance Report No.13 "Cancer Risk Coefficients for Environmental Exposure to Radionuclides" (Reference 14). These risk coefficient use the state of the art methods and models that take into account age and gender dependence of intake, metabolism, dosimetry, radiogenic risk, and competing causes of death in estimating the risk from exposure to radionuclides. Our DRLs for water are based on older dosimetry (Federal Guidance Report No. 11) and do not account for the differences in age and gender or changes in the most recent dosimetric and metabolic models. [Should have used up to date dose conversion factors]

To make this comparison we needed to estimate the cancer incidence risk using the dosimetry in this manual and the newer risk coefficients in Federal Guidance 13. Our DRLs are based upon the dosimetry that yields 0.5 rem in one year when drinking 2 liters of contaminated water per day. Using the most recent EPA risk factor of  $7.6 \times 10^{-4}$  cancers per rem (reference 9), our DRLs would yield a  $3.8 \times 10^{-4}$  cancer risk in one year (0.5 rem  $\times 7.6 \times 10^{-4}$  risk/rem =  $3.8 \times 10^{-4}$  cancer risk in one year).

10<sup>-4</sup> risk). EPA then compared this risk level to the risk level calculated using the Federal Guidance 13 risk coefficients.

1 2

Table G-7 contains the results of our comparison. The risk ratio, presented in the table, shows the difference between the two approaches. A ratio of 1.0 would mean that the DRL would yield the same risk level using both approaches. Ratios of greater than 1.0 would indicate that the Federal Guidance Report 13 risk coefficients would produce greater risk compared to the approach taken in this manual to derive the DRL. Those ratios showing a difference of a factor of two or greater are presented in bold type. Thirteen out of the 120 radionuclides have a ratio greater than 2.0. Thirty-one radionuclides (mostly alpha particle emitting radionuclides) have a ratio less than 0.5. All others agree within a factor of two. These results show that using the approach in this manual is still reasonable and somewhat conservative especially for the alpha particle emitting radionuclides.

Table G-7 Comparison of Risks: PAG Manual vs Federal Guidance Report No.13 Approach

Radionuclide	FG -13 Risk Coefficient	DRL (pCi/L) <sup>1</sup>	One-Year Cancer Risk <sup>2</sup>	Risk Ratio <sup>3</sup>
H-3	1.37e-12	1.07e+07	3.96e-04	1.04
C-14	4.20e-11	3.27e+05	3.71e-04	0.98
Na-22	2.60e-10	6.23e+04	4.37e-04	1.15
P-32	2.42e-10	7.79e+04	5.09e-04	1.34
P-33	2.65e-11	7.44e+05	5.33e-04	1.40
S-35	1.39e-11	1.52e+06	5.71e-04	1.50
Cl-36	8.92e-11	2.28e+05	5.50e-04	1.45
K-40	6.68e-10	3.60e+04	6.49e-04	1.71
Ca-45	6.68e-11	2.14e+05	3.86e-04	1.01
Sc-46	1.68e-10	1.07e+05	4.86e-04	1.28
Ti-44	6.93e-10	2.98e+04	5.57e-04	1.47
V-48	2.22e-10	7.96e+04	4.77e-04	1.26
Cr-51	5.01e-12	4.55e+06	6.15e-04	1.62
Mn-54	6.16e-11	2.45e+05	4.08e-04	1.07
Fe-55	2.33e-11	1.12e+06	7.07e-04	1.86
Fe-59	2.13e-10	8.67e+02	4.99e-06	0.01
Co-58	7.97e-11	2.28e+05	4.91e-04	1.29
Co-60	4.25e-10	2.54e+04	2.91e-04	0.77
Ni-63	1.81e-11	1.20e+06	5.88e-04	1.55
Zn-65	3.15e-10	4.90e+04	4.17e-04	1.10
Ge-68	7.64e-12	6.23e+05	1.28e-04	0.34

Draft G-13 3/21/2003

	Radionuclide	FG -13 Risk Coefficient	DRL (pCi/L) <sup>1</sup>	One-Year Cancer Risk <sup>2</sup>	Risk Ratio <sup>3</sup>
1	Se-75	2.20e-10	4.90e+04	2.91e-04	0.77
2	Rb-86	2.67e-10	7.29e+04	5.26e-04	1.38
3	Sr-89	3.47e-10	7.36e+04	6.90e-04	1.82
4	Sr-90	1.51e-09	4.90e+03	2.00e-04	0.53
5	Y-90	4.88e-10	6.23e+04	8.21e-04	2.16
6	Y-91	4.33e-10	7.20e+04	8.43e-04	2.22
7	Zr-93	2.01e-11	4.03e+05	2.19e-04	0.58
8	Zr-95	1.24e-10	1.46e+05	4.88e-04	1.28
9	Nb-94	2.10e-10	9.65e+04	5.48e-04	1.44
10	Nb-95	6.63e-11	1.46e+05	2.61e-04	0.69
11	Mo-99	4.33e-11	2.28e+05	2.67e-04	0.70
12	Tc-99	7.44e-11	4.55e+05	9.13e-04	2.40
13	Ru-103	1.04e-10	2.28e+05	6.41e-04	1.69
14	Ru/Rh-106	1.14e-09	2.54e+04	7.82e-04	2.06
15	Ag-110m	2.67e-10	6.23e+04	4.49e-04	1.18
16	Cd-109	1.35e-10	5.27e+04	1.92e-04	0.51
17	Cd-113m	7.77e-10	4.27e+03	8.97e-05	0.24
18	In-114m	6.70e-10	4.03e+04	7.30e-04	1.92
19	Sn-113	1.17e-10	2.21e+05	6.99e-04	1.84
20	Sn-123	3.78e-10	8.16e+04	8.33e-04	2.19
21	Sn-125	5.43e-10	5.71e+04	8.37e-04	2.20
22	Sn-126	6.91e-10	3.60e+04	6.71e-04	1.77
23	Sb-124	3.48e-10	6.99e+04	6.57e-04	1.73
24	Sb-126	3.00e-10	6.85e+04	5.55e-04	1.46
25	Sb-127	2.72e-10	1.02e+05	7.51e-04	1.98
26	Te-127	2.71e-11	8.25e+04	6.04e-05	0.16
27	Te-129	4.62e-12	3.42e+06	4.27e-04	1.12
28	Te-129m	4.14e-10	6.23e+04	6.96e-04	1.83
29	Te-131m	2.23e-10	7.53e+04	4.54e-04	1.19
30	Te/I-132		7.29e+04	0.00e+00	0.00
31	I-125	6.87e-10	1.81e+04	3.35e-04	0.88
32	I-129	3.99e-09	2.45e+03	2.64e-04	0.70
33	I-131	1.23e-09	1.29e+04	4.29e-04	1.13

Radionuclide	FG -13 Risk Coefficient	DRL (pCi/L) <sup>1</sup>	One-Year Cancer Risk <sup>2</sup>	Risk Ratio <sup>3</sup>
Cs-134	1.14e-09	9.38e+03	2.89e-04	0.76
Cs-136	2.34e-10	6.23e+04	3.94e-04	1.04
Cs/Ba137	8.22e-10	1.37e+04	3.04e-04	0.80
Ba-133	1.84e-10	2.02e+05	1.00e-03	2.64
Ba-140	4.03e-10	7.20e+04	7.84e-04	2.06
La-140	2.96e-10	8.16e+04	6.52e-04	1.72
Ce-141	1.25e-10	2.36e+05	7.96e-04	2.10
Ce-143	1.92e-10	1.49e+05	7.72e-04	2.03
Ce/Pr-144	9.54e-10	3.27e+04	8.42e-04	2.22
Nd-147	1.88e-10	1.56e+05	7.91e-04	2.08
Pm-145	1.51e-11	1.46e+06	5.95e-04	1.56
Pm-147	4.57e-11	6.85e+05	8.45e-04	2.22
Pm-149	1.80e-10	1.71e+05	8.33e-04	2.19
Pm-151	1.22e-10	2.28e+05	7.52e-04	1.98
Sm-151	1.50e-11	1.75e+06	7.11e-04	1.87
Eu-152	1.64e-10	1.05e+05	4.66e-04	1.23
Eu-154	2.79e-10	7.20e+04	5.43e-04	1.43
Eu-155	5.13e-11	4.55e+05	6.30e-04	1.66
Gd-153	4.12e-11	5.71e+05	6.35e-04	1.67
Tb-160	2.35e-10	1.02e+05	6.49e-04	1.71
Ho-166m	2.17e-10	8.46e+04	4.96e-04	1.30
Tm-170	2.41e-10	1.29e+05	8.41e-04	2.21
Yb-169	1.08e-10	2.28e+05	6.66e-04	1.75
Hf-181	1.72e-10	1.46e+05	6.77e-04	1.78
Ta-182	2.15e-10	1.05e+05	6.11e-04	1.61
W-187	9.92e-11	2.45e+05	6.57e-04	1.73
Ir-192	1.99e-10	1.20e+05	6.46e-04	1.70
Au-198	1.70e-10	1.63e+05	7.48e-04	1.97
Hg-203	1.54e-10	6.23e+04	2.59e-04	0.68
Tl-204	1.58e-10	2.02e+05	8.60e-04	2.26
Pb-210	2.38e-08	1.27e+02	8.16e-05	0.21
Bi-207	1.53e-10	1.24e+05	5.14e-04	1.35
Bi-210	2.41e-10	1.07e+05	6.97e-04	1.83

Table G-7 Comparison of Risks: PAG Manual vs Federal Guidance Report No.13 Approach

Radionuclide	FG -13 Risk Coefficient	DRL (pCi/L) 1	One-Year Cancer Risk <sup>2</sup>	Risk Ratio <sup>3</sup>
Po-210	4.97e-08	3.60e+02	4.83e-04	1.27
Ra-226	1.04e-08	5.27e+02	1.48e-04	0.39
Ac-227	5.43e-09	4.90e+01	7.19e-06	0.02
Th-227	1.28e-09	1.81e+04	6.24e-04	1.64
Th-228	2.90e-09	1.71e+03	1.34e-04	0.35
Th-230	2.46e-09	1.24e+03	8.27e-05	0.22
Th-232	2.73e-09	2.54e+02	1.87e-05	0.05
Pa-231	4.67e-09	6.20e+01	7.82e-06	0.02
U-232	7.88e-09	5.27e+02	1.12e-04	0.30
U-233	1.94e-09	2.36e+03	1.24e-04	0.33
U-234	1.91e-09	2.45e+03	1.26e-04	0.33
U-235	1.88e-09	2.54e+03	1.29e-04	0.34
U-238	1.73e-09	2.73e+03	1.28e-04	0.34
Np-237	1.67e-09	1.56e+02	7.04e-06	0.02
Np-239	1.39e-10	2.07e+05	7.79e-04	2.05
Pu-236	2.02e-09	5.71e+02	3.12e-05	0.08
Pu-238	3.55e-09	2.14e+02	2.05e-05	0.05
Pu-239	3.64e-09	1.95e+02	1.92e-05	0.05
Pu-240	3.65e-09	1.95e+02	1.92e-05	0.05
Pu-241	4.77e-11	1.01e+04	1.30e-05	0.03
Pu-242	3.46e-09	2.02e+02	1.89e-05	0.05
Am-241	2.81e-09	1.90e+02	1.44e-05	0.04
Am-242m	1.91e-09	1.95e+02	1.01e-05	0.03
Am-243	2.79e-09	1.90e+02	1.43e-05	0.04
Cm-242	1.04e-09	6.23e+03	1.75e-04	0.46
Cm-243	2.56e-09	2.73e+02	1.89e-05	0.05
Cm-244	2.26e-09	3.42e+02	2.09e-05	0.05
Cm-245	2.82e-09	1.85e+02	1.41e-05	0.04
Cm-246	2.76e-09	1.85e+02	1.38e-05	0.04

<sup>1</sup> From Table 4-2, DRL at 0.5 rem without radioactive decay 

<sup>&</sup>lt;sup>2</sup>One-year cancer risk from drinking 2 liters per day at the DRL using Federal Guidance 13 risk factors

<sup>&</sup>lt;sup>3</sup> Ratio of Cancer risks: Column 4 divided by the risk from 0.5 rem (3.8 e-04)

1		References
2 3	1.	U.S. Federal Emergency Management Agency. "Radiological Emergency Planning and Preparedness," 44 CFR Part 351, Federal Register, Vol. 47, and 48, March 11, 1982.
4 5 6	2.	U.S. Environmental Protection Agency. "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," EPA 400-R-92-001, Washington, D.C., May 1992.
7 8 9	3.	Sanford Cohen & Associates. "Exposure Pathways For Water," Prepared for EPA Office of Radiation and Indoor Air under Contract No. 68D90170, Work Assignment No. 1-43, April 1991.
10 11 12	4.	Jack Faucett Associates. "Cost of Providing Alternate Drinking Water to a Community Following a Nuclear Contamination Incident," Prepared for EPA Office of Radiation and Indoor Air under Contract No. 68020156, Work Assignment 1-2, August 1993.
13 14 15 16	5.	Sanford Cohen & Associates. "Evaluation of Alternative Protective Action Guide Options and Implementation Guidelines for Drinking Water," Prepared for EPA Office of Radiation and Indoor Air under Contract No. 68020156, Work Assignment No. 1-12, September 1993.
17 18	6.	U.S. Environmental Protection Agency. "Guidelines for Performing Regulatory Impact Analysis," EPA-230-84-003, Washington D.C., December 1983.
19 20 21	7.	Food and Drug Administration, B. Burnett, et al, "Accidental Radioactive Contamination of Human Food and Animal Feed; Recommendation for State and Local Agencies," Revised Guidance, DRAFT, December 23, 1991.
22 23 24	8.	International Commission on Radiological Protection. "Protection of the Public in the Event of Major Radiation Accidents: Principles for Planning." Oxford: Pergamon Press; ICRP Publication 40; Ann. ICRP 14(2); 1984.
25 26 27	9.	International Commission on Radiological Protection. "Limits for Intakes of Radionuclides by Workers." Oxford: Pergamon Press; ICRP Publication 30; Ann. ICRP 2(3/4); 1979
28 29 30	10.	International Commission on Radiological Protection. "Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 1." Oxford: Pergamon Press; ICRP Publication 56; Ann. ICRP 20(2); 1989.
31 32 33	11.	International Commission on Radiological Protection. "Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 2." Oxford: Pergamon Press; ICRP Publication 67; Ann. ICRP 23(3/4); 1993.

Draft G-17 3/21/2003

- 1 12. International Commission on Radiological Protection. "Age-dependent Doses to
  2 Members of the Public from Intake of Radionuclides: Part 3." Oxford: Pergamon Press;
  3 ICRP Publication 69; Ann. ICRP 25(1); 1995.
- International Commission on Radiological Protection. "Age-Dependent Doses to
   Members of the General Public from Intakes of Radionuclides. Oxford: Pergamon; ICRP
   Publication 72. Press; Ann. ICRP 26(1) 1996.
- U.S. Environmental Protection Agency. "Cancer Risk Coefficients for Environmental
   Exposure to Radionuclides. Federal Guidance Report No. 13. EPA 402-R-99-001,
   September 1999.

Draft G-18 3/21/2003

# Explanation of "3 Tables Comparing 500 mrem/yr DRL Concentrations to MCL or 1 x 10<sup>-4</sup> Concentrations"

There are 3 Lotus 123 Tables provided. They are sorted by:

- 1. Radionclide, in the order provided in the draft PAGs chapter
- 2. Risk, in order of the DRL posing the highest multiple of a 1 x 10-4 cancer incidence risk
- 3. MCLs, in order of the DRL posing the greatest multiple of the MCL

## **Rationale for Tables 2 and 3:**

The CERCLA document most analogous to this PAG would be the "Final Guidance on Numeric Removal Action Levels for Contaminated Drinking Water Sites" OSWER 9360.1-02, October 25, 1993, which discusses when short-term risks from contaminated drinking water wells are high enough to warrant providing alternative (replacement) drinking water supplies. For class A carcinogens that do not have DWELs or longer-term HA's, like radionuclides, this guidance says to provide drinking water if the concentrations are above 1 x 10<sup>-4</sup> lifetime risk (using OW methodology of 70 year exposure), or the MCL, if the MCL is greater than 1 x 10<sup>-4</sup> lifetime risk.

Following are explanations of the information in the 3 tables.

## Radionuclide column:

- Lists of radionuclides taken from Table 4.2 in draft Chapter 4 on drinking water PAGs.
- Radionuclides that are bolded and their rows are shaded were considered radionuclides of
  most concern for RDDs, INDs, or nuclear accidents in writeups from ORIA and Army
  Corps of Engineers.
- Tables that were put in the same row in Table 4.2 (e.g., Ru/Rh-106) have been broken out to facilitate comparisons between DRLs and  $1 \times 10^{-4}$  risk levels.

#### **DRLs with Rad Decay column:**

• Taken from Table 4.2. These were the most stringent DRLs listed and were used for comparison purposes since the other DRLs used assumptions that would not factor into CERCLA decisions about when to provide drinking water (e.g., assuming levels will decay or dilute over the year so use a level averaged over the year).

#### 1x10-4 using OW Methods column:

- For those radionuclides that **do** have a value listed in the column "OW risk associated with MCL", these values are based on the rounded off values in the "OW risk..." column then a hand calculation on the value in the "MCLs" column to approximate the concentration that corresponds to a 1 x 10<sup>-4</sup> cancer incidence risk using OW methodology. Note, OW staff did not create 1 x 10<sup>-4</sup> concentrations for these radionuclides.
- For those radionuclides that **do not** have a value listed in the column "OW risk associated with MCL", these values are from OW.

#### **MCLs Column:**

- MCLs from OW implementation guide.
- Uranium MCLs are in terms of mass (micrograms per liter), not activity (picoCuries per liter). The 30 micrograms per liter MCL for the uranium element was converted to an activity for each isotope. The UMTRCA groundwater standard of 30 pCi/l for U-234 and U-238 combined was listed here for U-234 since it is a potential ARAR at CERCLA sites.

#### **OW Risk Associated with MCL**

• Provided in NODA for MCLs and/or regulatory support document. Note that some MCLs that are in OW implementation guide did not appear in the support documents, which is why SF rather than OW risk is provided.

#### 1x10-4 using SF & 70 yrs

• Risk estimate developed using CERCLA rad PRG calculator, by changing "Tap water" exposure scenario defaults as follows: time of exposure from 30 years to 70 years; target risk from  $1 \times 10^{-6}$  to  $1 \times 10^{-4}$ .

#### Comparison of DRL to OW/SF 10-4:

• Shows by a factor of #, how much DRL is greater than  $1 \times 10^{-4}$  risk level concentration.

#### • What this means

- if value is 70, then **1 year** of drinking 2 liters of water at DRL value will equal amount of exposure of drinking water with a lifetime cancer incidence risk of 1 x 10<sup>-4</sup> for a lifetime (70 years)
- if value is 840, then 1 month of drinking 2 liters of water at DRL value will equal amount of exposure of drinking water with a lifetime cancer incidence risk of 1 x 10<sup>-4</sup> for a lifetime (70 years)
- if value is 25,550, then 1 day of drinking 2 liters of water at DRL value will equal amount of exposure of drinking water with a lifetime cancer incidence risk of 1 x 10<sup>-4</sup> for a lifetime (70 years)
- if value is 127,750, then drinking **1 glass** of water (12 ounces) at DRL value will equal amount of exposure of drinking water with a lifetime cancer incidence risk of 1 x 10<sup>-4</sup> for a lifetime (70 years)

## **Comparison of DRL to MCL**

• Shows by a factor of #, how much DRL is greater than MCL concentration.

#### • What this means

- if value is 70, then **1 year** of drinking 2 liters of water at DRL value will equal amount of exposure of drinking water at the MCL level for a lifetime (70 years)
- if value is 840, then **1 month** of drinking 2 liters of water at DRL value will equal amount of exposure of drinking water at the MCL level for a lifetime (70 years)
- if value is 25,550, then **1 day** of drinking 2 liters of water at DRL value will equal amount of exposure of drinking water at the MCL level for a lifetime (70 years)
- if value is 127,750, then drinking 1 glass of water (12 ounces) at DRL value will equal amount of exposure of drinking water at the MCL level for a lifetime (70 years).
  - For example, drinking a very small glass of water of approximately 4ounces with Bi-210 at the DRL concentration would result in an exposure that corresponds to drinking liters of water per day for 70 years at the MCL level.

Sorted by OW/SF 1x10-4 Cancer Incidence Risk Table Comparing 500 mrem/yr DRL Concentrations to MCL or 1 x 10-4 Concentrations Sheet1

		Radionuclide	Cs-134	Pm-151	W-187	Te-131m	Np-239	Ce-143	Co-58	Te-132	La-140	Pm-149	Sb-127	Au-198	Y-90	Bi-210	Te-129	Mo-99	Ge-68	Sb-126	Sn-125	Nd-147	Th-227	Ba-140	V-48	I-131	P-32	Yb-169	P-33	Rb-86	Ru-103	1-129	Cs-136	Ce-141	Te-129m
DRI &	without	de Rad Decay	37900	50000000	62700000	15400000	22700000	27800000	1640000	5850000	12500000	20000000	7080000	16100000	6140000	5850000	313000000	21600000	2820000	1650000	1710000	4130000	309000	1680000	1540000	450000	1640000	2660000	10000000	1250000	3820000	90900	1430000	2660000	702000
Concentrations in pCi/L	using	OW Methods	0.26666667		1000			500	33.33333333		300	500		500	198	219	20000	1500			198	500	.41	225		75	300			300	1000	25	400	750	225
<u> </u>	nga est		80		200	200	300	100	300	90	60	100		100	60	15	2000	600			60	200	15	90		သ	30			600	200	_	800	300	90
OW Bisk	Associated		3x10-2		2x10-5			2x10-5	9x10-4		2×10-5	2x10-5		2x10-5	3x10-5		1x10-5	4x10-5			3x10-5	4×10-5		4x10-5		4x10-6	1x10-5			2x10-4	2x10-5	4×10-6	2x10-4	4x10-5	4x10-5
	using	SF & 70yrs		453		247	397			120			202						293	184					249			510	2080						
Comparison shows DRL is X times 10-4 or MCL value	of DRL to	OW/SF 10-4	142125	110375.2759	62700	62348.17814	57178.84131	55600	49200	48750	41666.66667	40000	35049.50495	32200	31010.10101	26712.32877	15650	14400	9624.573379	8967.391304	8636.363636	8260	7536.585366	7466.666667	6184.738956	6000	5466.666667	5215.686275	4807.692308	4166.666667	3820	3636	3575	3546.666667	3120
	of DRL to	MCL	473.75		313500	77000	75666.66667	278000	5466.666667	65000	208333.3333	200000		161000	102333.3333	390000	156500	36000			28500	20650	20600	18666.66667		150000	54666.66667			2083.333333	19100	90900	1787.5	8866.666667	7800

Page 1

	9683.333333	0069	4550	6411.11111		2866.666667	4533.333333	7280	7250		9316.666667		131.3333333	4300	8470	2550		19800	2210		4933.333333	3700	7120		4483.333333		1877.77778	6540	2606.666667	00059		6140	112000	1252.857143	3233.333333	312.222222	89200	2916.666667		763.3333333	
	2934.343434	2760	2757.575758	2564.44444	2533.333333	2346.666667	2247.933884	2206.060606	2196.969697	1950	1863.333333	1800	1790.909091	1720	1694	1681.818182	1614.457831	1584	1578.571429	1495.890411	1494.949495	1480	1424	1387.5	1358.585859	1350	1341.269841	1308	1303.333333	1300	1236.220472	1228	1009.009009	1002.285714	979.7979798	936.6666667	892	883.8383838	819.5876289	763.3333333	
					300		1210			80		80					83			3650				80		340					254								1940		
Sheet1	3x10-5	4×10-5	6x10-5	4x10-5		4×10-5		3x10-5	3x10-5		2x10-5			4×10-5	2x10-5	3x10-5		8x10-6	7×10-5		3x10-5	4×10-5	2x10-5		3x10-5		7x10-5	2x10-5	5x10-5	2x10-6		2×10-5	9×10-7	8x10-5	3x10-5	3x10-4	1x10-6	3x10-5		1×10-4	
S	0009	200	09	06		09	900	100	100		09		15	300	100	200		200	2000		30	30	100		009		006	1000	300	06		100	10	200	06	900	20	009		300	
	19800	200	66	225		150		330	330		300		1.1	750	200	099		6250	2800		66	75	200		1980		1260	2000	009	4500		200	1110	875	297	300	2000	1980		300	
	58100000	1380000	273000	577000	760000	352000	2720000	728000	725000	156000	559000	144000	1970	1290000	847000	1110000	134000	0000066	4420000	5460000	148000	111000	712000	111000	2690000	459000	1690000	6540000	782000	5850000	314000	614000	1120000	877000	291000	281000	4460000	1750000	1590000	229000	
	Cr-51	Hf-181	F11-154	Y-91	Ba-133	In-114m	Pm-147	Tb-160	Tm-170	Sn-126	Sb-124	1-125	Po-210	Sn-113	Ir-192	Zr-95	K-40	S-35	Fe-55	Pm-145	Ce-144	Ru-106	Sc-46	Ti-44	Gd-153	Sn-123	Tc-99	Sm-151	TI-204	1-132	Ho-166m	Ta-182	Ca-45	CI-36	Ag-110m	Se-75	N:-63	F11-155	Nb-95	Zn-65	

Am-241 706 Am-243 706 Cm-246 688 Cm-245 688			_		Cm-244 1280					H-3 10700000		Cd-113m 16100	J		U-233 8770		11-234 9090	U-235 9420 U-238 10200	9 22		Ra-226 1950											
19 19 19	à		21	19	23	39	26	2970	2000	50000	21			Ď.		CMITACA	I IMTRCA GW		600	18		<b>5</b> 1	40 5	100 200 40 5	N -1 (0							
15 15 15 15	<b>.</b>		15	15	15	15	15	900	200	20000	15			640000000	290000	190000	3 <b>-</b>	65	600	15		<b>5</b> 1	51 88 5	200 100 8	60 <b>200</b> <b>8</b> <b>8</b>	60 <b>200</b> 8	2000 60 <b>200</b> 100 8	400 2000 60 <b>200</b> <b>100</b> 8	15 400 2000 60 <b>200</b> 100 8	20 15 400 2000 60 <b>200</b> <b>100</b> 8	200 20 15 400 2000 60 <b>200</b> <b>100</b> 8	300 200 20 15 400 2000 60 <b>2000</b> <b>8</b>
								3x10-5	1x10-5	4x10-5									1x10-4		-4-0-4	1410 4	2x10-5	2x10-4 5x10-5 2x10-5	6×10-4 2×10-4 5×10-5 2×10-5	6×10-4 2×10-4 5×10-5 2×10-5	1×10-4 6×10-4 2×10-4 2×10-5	1×10-4 1×10-4 6×10-4 5×10-5 2×10-5	1×10-4 1×10-4 6×10-4 5×10-4 2×10-5	2x10-6 1x10-4 1x10-4 1x10-4 6x10-4 2x10-5 2x10-5	3x10-5 2x10-6 1x10-4 1x10-4 1x10-4 6x10-4 5x10-5 2x10-5	2x10-5 3x10-5 2x10-6 1x10-4 1x10-4 1x10-4 6x10-4 2x10-5 2x10-5
	16	À 5		ā	ò							71	N ·	7	28	29	) <b>(</b>	3 3 3 3								613	613	613	613	613	613	613
37.21052632 37.15789474 36.21052632 36.21052632	48.46666667 46.8125	48.46666667	48.57142857	49.737 49.57894737	55.65217391	63.07692308	86.53846154	164.983165	197	214	220.4761905	226.7605634	238	280	313.2142857	313,4482759	313 4483750	324.8275862	370	385.555556	390		486.5	512 486.5 455	571.7171717 <b>512</b> <b>486.5</b> <b>455</b>	582.3817292 571.7171717 <b>512</b> <b>486.5</b>	605 582.3817292 571.7171717 <b>512</b> <b>486.5</b>	615 605 582.3817292 571.7171717 <b>512</b> <b>486.5</b>	637.254902 615 605 582.3817292 571.7171717 <b>512</b> <b>486.5</b>	643 637.254902 615 605 582.3817292 571.7171717 <b>512</b> <b>486.5</b>	707.5757576 643 637.254902 615 605 582.3817292 571.7171717 512 486.5	726.6666667 707.5757576 643 637.254902 615 605 582.3817292 571.7171717 512 486.5

51200

Table Comparing 500 mrem/yr DRL Concentrations to MCL or 1 x 10-4 Concentrations Sorted by MCL Sheet1

Page 1	60 60 <b>3</b> 00	1640000     300     30     1x10-5       21600000     1500     600     4x10-5       643000     1000     20     2x10-6       1710000     198     60     3x10-5       4130000     500     200     4x10-5       309000     41     15       9900000     6250     500     8x10-6       3820000     1000     200     2x10-5       1680000     225     90     4x10-5       58100000     19800     6000     3x10-5       586000     19800     6000     3x10-5	5850000 219 15 62700000 1000 200 2x10-5 43 27800000 500 100 2x10-5 49 20000000 500 100 2x10-5 98 16100000 20000 100 2x10-5 29 313000000 75 3 4x10-5 6140000 198 60 3x10-5 90900 25 1 4x10-6 91m 15400000 4500 90 5850000 4500 90 2x10-6 90900 25 1 4x10-6 91m 15400000 5000 5000 90 5850000 4500 90	ο.
Page 1	6x10-4 2x10-5 4x10-5 <b>2x10-5</b>		9 9 9 9 9 9 9 9 9 9 9 9	e E
	571.7171717 1863.333333 3546.666667 <b>1694</b>		0 77	Comparison of DRL to
	9433.333333 9316.666667 8866.666667 <b>8470</b>	54666.66667 36000 32150 28500 20650 20650 19800 19800 18666.66667 9683.333333	390000 313500 278000 208333.333 200000 161000 156500 156500 112000 112333.3333 90900 89200 77000 75666.66667 65000	Con

	7800	7280	7250	7120	0069	6540	6411.11111	6140	2866.666667	5550	5466.666667	4933.333333	4550	4533.333333	4483.333333	4300	3700	3633.333333	3233.333333	2916.666667	2606.666667	2335	2275	2210	2166.666667	2083.333333	1970	1877.77778	1787.5	1252.857143	1020	973	830	763.333333	615	909	544.444444
	3120	2206.060606	2196.969697	1424	2760	1308	2564.44444	1228	2346.666667	1681.818182	49200	1494.949495	2757.575758		1358.585859	1720	1480	726.6666667	979.7979798	883.8383838	1303.333333	707.5757576	455	1578.571429	637.254902	4166.666667	197	1341.269841	3575	1002.285714	2 318.75	486.5	754.5454545	763.333333	615	909	164.983165
														1210																	32						
Sheet1	4×10-5	3x10-5	3x10-5	2x10-5	4×10-5	2×10-5	4×10-5	2x10-5	4×10-5	3x10-5	9x10-4	3x10-5	6x10-5		3x10-5	4x10-5	4×10-5	2x10-5	3x10-5	3x10-5	5×10-5	3×10-5	2×10-5	7×10-5		2x10-4	1x10-5	7×10-5	2×10-4	8x10-5		5×10-5	9x10-5	1x10-4	1×10-4	1x10-4	3x10-5
	06	100	100	100	200	1000	06	100	9	200	300	30	09	009	009	300	30	300	06	009	300	200	80	2000	15	009	200	900	800	200	10	100	2000	300	400	2000	006
	225	330	330	200	200	2000	225	200	150	099	33,3333333	66	66		1980	750	75	1500	297	1980	009	099	40	2800	51	300	2000	1260	400	875		200	2200	300	400	2000	2970
	702000	728000	725000	712000	1380000	6540000	577000	614000	352000	1110000	1640000	148000	273000	2720000	2690000	1290000	111000	1090000	291000	1750000	782000	467000	18200	4420000	32500	1250000	394000	1690000	1430000	877000	10200	97300	1660000	229000	246000	1210000	490000
	Te-129m	Tb-160	Tm-170	Sc-46	Hf-181	Sm-151	Y-91	Ta-182	In-114m	7r-95	Co-58	Ce-144	F11-154	Pm-147	Gd-153	Sn-113	R11-106	Mn-54	An-110m	Fu-155	TI-204	Bi-207	Sr-90	Fe-55	Cm-242	Rb-86	Eu-152	Tc-99	Cs-136	CI-36	U-238	Co-60	Zr-93	Zn-65	Na-22	C-14	Te-127

Cd-113m Sb-127	Pu-238 Pu-239 Pr-144 Ac-227 Pu-240	Np-237 Pa-231 U-234 U-233 U-232 Pu-242 Am-242m	<b>Am-241</b> Am-243 Cm-246 Cm-245 Fe-59	Cf-252 Pu-236 U-235 Po-210 Pu-241 Cm-244 Cm-243 Th-232	H-3 Cs-134 Th-228 Ra-226 Cd-109 Se-75 Th-230 U-234 Cs-137
16100 7080000	796 727 148000 183 727	578 231 9090 8770 1960 <b>749</b> 728	706 706 688 688 8200	2460 2250 <b>9420</b> 1970 1970 1280 1020 942	
		8 2 8	19 19 19 19 400	39 26 27 21 21 21	50000 0.26666667 18 5 600 300 21 UMTRCA GW
		15 15 190000 290000 640000000	15 15 15 200	300 300 300 300	20000 80 15 600 900 15 30
			5×10-5	1	4x10-5 3x10-2 1x10-4 1x10-4 3x10-4
71 202	16 15 25200 10 15	29 28 7 <b>16</b> 29		29 1160	29
226.7605634 35049.50495	49.75 48.4666667 5.873015873 18.3 48.46666667	18.0625 28.875 313.4482759 313.2142857 280 <b>46.8125</b> 25.10344828	37.21052632 37.15789474 36.21052632 36.21052632 36.21052632 20.5	324.8275862 1790.909091 32.67241379 55.65217391 48.57142857 49.57894737	214 142125 385.555556 390 370 936.6666667 220.4761905 313.4482759
		38.5333333 15.4 0.047842105 0.030241379 3.0625E-06	47.1333333 47.06666667 45.86666667 45.86666667	144.9230 131.3333 126.3333 85.33333	535 473.75 462.6666667 390 370 312.2222222 308.66666667 303

	1950	819.5876289	110375.2759	1350	1387.5	1495.890411	1614.457831	1800	582.3817292	9624.573379	2533.333333	4807.692308	5215.686275	6184.738956	238	1236.220472	8967.391304	
	80	1940	453	340	80	3650	83	80	613	293	300	2080	510	249	2	254	184	
Sheet1																		
	156000	1590000	20000000	459000	111000	5460000	134000	144000	357000	2820000	760000	10000000	2660000	1540000	476	314000	1650000	51200
	Sn-126	Nb-95	Pm-151	Sn-123	Ti-44	Pm-145	K-40	1-125	Nb-94	Ge-68	Ba-133	P-33	Yb-169	V-48	Pb-210	Ho-166m	Sb-126	Ba-137

Table Comparing 500 mrem/yr DRL Concentrations to MCL or 1 x 10-4 Concentrations Sorted by Radionuclide Sheet1

	Soried by Kauloniuchide	ollucilue					
		Concentrations in nCi/L	n pCi/L			Comparison shows DRL is X times 10-4 or MCI value	vs DRL is
	DRLs	1x10-4	MCLs	OW Risk	1x10-4	Comparison	Comparison
	without	using		Associated	using	of DRL to	of DRL to
Radionuclide	Rad Decay	<b>OW Methods</b>		with MCL	SF & 70yrs	OW/SF 10-4	MCL
H-3	10700000	50000	20000	4x10-5		214	535
C-14	1210000	2000	2000	1x10-4		605	605
Na-22	246000	400	400	1x10-4		615	615
P-32	1640000	300	30	1x10-5		5466.666667	54666.66
P-33	10000000				2080	4807.692308	
S-35	9900000	6250	500	8x10-6		1584	19800
CI-36	877000	875	700	8x10-5		1002.285714	1252.857143
K-40	134000				83	1614.457831	
Ca-45	1120000	1110	10	9x10-7		1009.009009	112000
Sc-46	712000	500	100	2x10-5		1424	7120
Ti-44	111000				80	1387.5	
V-48	1540000				249	6184.738956	
Cr-51	58100000	19800	6000	3x10-5		2934.343434	9683.333333
Mn-54	1090000	1500	300	2x10-5		726.6666667	3633.333333
Fe-55	4420000	2800	2000	7x10-5		1578.571429	2210
Fe-59	8200	400	200	5x10-5		20.5	41
Co-58	1640000	33.33333333	300	9x10-4		49200	5466.666667
Co-60	97300	200	100	5x10-5		486.5	973
Ni-63	4460000	5000	50	1x10-6		892	89200
Zn-65	229000	300	300	1x10-4		763.3333333	763.3333333
Ge-68	2820000				293	9624.573379	
Se-75	281000	300	900	3x10-4		936.6666667	312.2222222
Rb-86	1250000	300	600	2x10-4		4166.666667	2083.333333
Sr-89	643000	1000	20	2x10-6		643	32150
Sr-90	18200	40	8	2x10-5		455	2275
Y-90	6140000	198	60	3x10-5		31010.10101	102333.3333
Y-91	577000	225	90	4x10-5		2564.444444	6411.111111
Zr-93	1660000	2200	2000	9x10-5		754.5454545	830
Zr-95	1110000	660	200	3x10-5		1681.818182	5550
Nb-94	357000				613	582.3817292	
				<b>.</b>			

Page 1

		36000	1877.77778	19100	3700		3233.333333	370		5866.666667	4300	A STATE OF S	28500	32	9316.666667			544,444444	156500	7800	77000	65000	65000		00606	150000	473.75	1787.5	256			18666.66667	208333.3333	8866.666667	278000	4933.333333	
	819.5876289	14400	1341.269841	3820	1480		979.7979798	370	226.7605634	2346.666667	1720	1350	8636.363636	1950	1863.333333	8967.391304	35049.50495	164.983165	15650	3120	62348.17814	48750	1300	1800	3636	0009	142125	3575	512		2533,333333	7466.666667	41666.66667	3546.666667	22600	1494.949495	5.873015873
	1940								71			340		80		184	202				247	120		80							300						25200
Sheet1		4×10-5	7×10-5	2×10-5	4x10-5		3x10-5	1×10-4		4×10-5	4×10-5		3×10-5		2×10-5			3×10-5	1x10-5	4×10-5			2×10-6		4×10-6	4x10-6	3×10-2	2x10-4	2×10-4			4×10-5	2x10-5	4x10-5	2×10-5	3x10-5	
		009	006	200	30		06	009		09	300		09		09			006	2000	06	200	06	06		~	က	80	800	200			06	09	300	100	30	
		1500	1260	1000	75		297	009		150	750		198		300			2970	20000	225			4500		25	75	0.266666667	400	100			225	300	750	200	66	
	1590000	21600000	1690000	3820000	111000	111000	291000	222000	16100	352000	1290000	459000	1710000	156000	223000	1650000	7080000	490000	313000000	702000	15400000	5850000	5850000	144000	00606	450000	37900	1430000	51200	51200	260000	1680000	12500000	2660000	27800000	148000	148000
	NP-95	Mo-99	Tc-99	Ru-103	Ru-106	Rh-106	Ag-110m	Cd-109	Cd-113m	In-114m	Sn-113	Sn-123	Sn-125	Sn-126	Sb-124	Sb-126	Sb-127	Te-127	Te-129	Te-129m	Te-131m	Te-132	I-132	1-125	1-129	1-131	Cs-134	Cs-136	Cs-137	Ba-137	Ba-133	Ba-140	La-140	Ce-141	Ce-143	Ce-144	Pr-144

age 2

Neet1  77 4130000 500 200 4x10-5 8260  45 54600000 500 100 2x10-5 1210 2247.933844  48 20000000 500 100 2x10-5 453 11375.2759  51 6540000 500 100 2x10-5 453 11375.2759  52 394000 2000 2000 1x10-5 1368.8848338383  28900000 1980 600 3x10-5 2757.57578  44 273000 99 60 3x10-5 2757.57578  45 1750000 330 100 3x10-5 254 1238.238383  2890000 1980 600 3x10-5 510 528.68689  725000 330 100 3x10-5 510 528.68689  725000 330 100 3x10-5 510 528.68687  614000 500 200 4x10-5 1228  627000 500 100 2x10-5 510 528.68687  847000 500 100 2x10-5 510 528.68687  847000 500 100 2x10-5 510 528.68687  847000 500 100 2x10-5 620  847000 500 100 2x10-5 510 528.68687  8487000 500 100 2x10-5 510 528.686276  1228 62700 100 2x10-5 510 528.77.717177  1228 6270-5 510 528.686276  1228 62700 100 2x10-5 510 528.77.717777  1228 6270-5 510 528.686276  1228 62700 100 2x10-5 510 528.77.717777  1228 62700 100 2x10-5 510 528.586565  1150 1150 115 15 15 15 15 15 15 15 15 15 15 15 15	141.02.00	027.021.0002	ţ	j	ć			1
77         4130000         500         200         Ancett           45         5460000         600         200         4x10-5         3650         1495,890411           47         2720000         600         100         2x10-5         1210         2247,93384         4533.3           49         20000000         5000         1000         2x10-5         453         110375,2759         1308           51         50000000         1980         600         2x10-5         453         110375,2759         1308           22         20000000         1980         600         3x10-5         883,833338         2916,6           4         2730000         1980         600         3x10-5         138,858589         4483.3           4         2730000         1980         600         3x10-5         254         1328,858589         4483.3           2680000         330         100         3x10-5         254         1238,85859         4483.3           47000         330         100         3x10-5         254         1238,85859         4483.3           487000         500         200         4x10-5         510         5215,686275         2760,686897 <td>144 9230</td> <td>324 8275862</td> <td>90</td> <td></td> <td>65</td> <td></td> <td>9420</td> <td>U-235</td>	144 9230	324 8275862	90		65		9420	U-235
77         4130000         500         200         Meett           45         5460000         600         200         4x10-5         3650         1495 890411           47         2720000         600         100         2x10-5         1210         2247 933884         4533 3           49         20000000         5000         1000         2x10-5         453         110375 2759           51         5000000         5000         1000         2x10-5         453         110375 2759           197         272000         5000         1000         2x10-5         453         110375 2759           198         600         3x10-5         838383838         2916 6         600         3x10-5         838383838         2916 6           44         273000         1980         600         3x10-5         254         1236 586869         4483 3           2800000         1980         600         3x10-5         254         1236 586869         4483 3           41         2800000         330         100         3x10-5         254         1236 586869         4483 3           52         1380000         500         100         2x10-5         510         5216	•	313.4482759	29		30	<b>UMTRCA GW</b>	9090	U-234
77     4130000     500     200     ANTO-E       45     5400000     500     200     4x10-5     8260       47     2720000     600     100     2x10-5     1210     2247.933884     4533.3       49     20000000     500     100     2x10-5     1210     2247.933884     4533.3       500000000     500     1000     2x10-5     1210     2247.933884     4533.3       40000     2000     1x10-5     13075.2759     1308       40000     2000     1x10-5     13075.2759     1308       50     334000     200     200     1x10-5     275.75758     138       60     725000     1980     600     3x10-5     254     1238.28333     2916.6       60     725000     330     100     3x10-5     254     1238.280472       725000     330     100     3x10-5     254     1238.280472       725000     330     100     3x10-5     254     1238.280472       725000     330     100     3x10-5     510     586.86697       728000     500     200     2x10-5     510     586.86697       728000     500     200     2x10-5     510     586.86	0.0478421	313.4482759	29		190000		9090	U-234
77     4130000     500     200     ANTO-5     8250       45     5400000     600     200     4x10-5     8250       47     2720000     600     100     2x10-5     1495.890411       49     20000000     500     100     2x10-5     453     110375.2759       49     20000000     500     1000     2x10-5     453     110375.2759       40000     2000     2000     2x10-5     453     110375.2759       44     273000     99     60     600     3x10-5     883.838383     2916.6       5     1750000     1980     600     3x10-5     2250.60606     483.3       6     725000     330     100     3x10-5     256.836559     4483.3       6     725000     330     100     3x10-5     256.836569     4483.3       725000     330     100     3x10-5     256.836569     4483.3       8     1610000     500     200     4x10-5     254     1236.236472       7     1380000     500     100     2x10-5     510     5215.686275       7     1380000     500     100     2x10-5     510     5215.686276     270       7     2860	0.0302413	313.2142857	28		290000		8770	U-233
7     413000     500     200     Athett       5     5460000     600     200     4x10-5     8260       5     5460000     600     1205     8260     1495.890411       7     2720000     600     100     2x10-5     1210     2247.933844     4533.2       9     20000000     500     100     2x10-5     453     110375.2759     247.933844     4533.2       1     65000000     500     100     2x10-5     453     110375.2759     130       1     65000000     500     200     1x10-5     275.575758     139       1     750000     1980     600     3x10-5     883.838383     2916.6       1     750000     1980     600     3x10-5     883.838383     2916.6       1     750000     1980     600     3x10-5     254     1236.20472       1     750000     330     100     3x10-5     254     1236.20472       2     750000     330     100     3x10-5     254     1236.20472       2     750000     300     100     2x10-5     254     1236.20472       2     7516.86600     200     2x10-5     510     2516.86606 <tr< td=""><td>3.0625E</td><td>280</td><td>7</td><td></td><td>640000000</td><td></td><td>1960</td><td>U-232</td></tr<>	3.0625E	280	7		640000000		1960	U-232
7         4130000         500         200         4x10-5         8260           5         5460000         600         200         4x10-5         8260         1495.890411           7         2720000         600         100         2x10-5         1210         2247.933844         4533.3           9         20000000         5000         1000         2x10-5         453         110375.7759         247.933844         4533.3         10000         2210-5         40000         2247.933844         4533.3         247.933844         4533.3         247.933844         4533.3         247.933844         4533.3         257.575759         10000         2210-5         1000         2210-5         1000         2210-5         1000         2210-5         1000         2210-5         1000         2210-5         1000         2210-5         1000         2210-5         1000         200-5         254         1236.58859         2483.3         2916.6 <td< td=""><td>_</td><td>28.875</td><td></td><td></td><td>15</td><td>8</td><td>231</td><td>Pa-231</td></td<>	_	28.875			15	8	231	Pa-231
4130000       500       200       At10-5       8260         5       5460000       600       200       4x10-5       8260         7       2720000       600       1210       2247,933884       4533.3         8       20000000       500       100       2x10-5       453       110375,2759       2         1       6540000       500       1000       2x10-5       453       110375,2759       198         25000000       5000       1000       2x10-5       453       110375,2759       198         25000000       1980       600       6x10-5       275,75758       883,383833       2916,6         2500000       1980       600       3x10-5       883,383833       2916,6         2500000       1980       600       3x10-5       254       1256,58565       483,3         728000       330       100       3x10-5       254       1236,20472       216,68657       216,68657       216,68657       128,08697       128,0000       483,3       100       2x10-5       510       5215,68565       448,3       128,0000       100       2x10-5       510       5215,68567       128,0000       128,000       128,000       128,000	6	49.57894737			15	19	942	Th-232
4130000     500     200     4170000       5     5460000     600     4x10-5     3650     1495.89411       7     2720000     600     1210     2247.933844     4533.3       8     20000000     500     100     2x10-5     453     110375.2759       1     6540000     500     1000     2x10-5     453     110375.2759     1308       1394000     2000     200     1x10-5     2757.575758     1308     1308       1750000     1980     600     3x10-5     2575.75758     2757.57578     2916.6       1750000     1980     600     3x10-5     254     1236.85859     4483.3       7280000     1980     600     3x10-5     254     1236.85859     4483.3       7280000     330     100     3x10-5     254     1236.85859     4483.3       7280000     330     100     3x10-5     254     1236.85859     4483.3       847000     330     100     3x10-5     254     1236.85859     4483.3       847000     500     100     2x10-5     510     5215.868275     1228       1610000     500     100     2x10-5     510     5215.868276     1228       <	308.66666	220.4761905			15	21	4630	Th-230
4130000     500     200     4x10-5     8260       5     5460000     600     200     4x10-5     8260       7     2720000     600     100     2x10-5     453 89411       7     2720000     500     100     2x10-5     453 110375.2759       9     20000000     500     100     2x10-5     453 110375.2759       1     6540000     500     100     2x10-5     453 110375.2759       1     394000     200     1x10-5     453 110375.2759       1     394000     200     2x10-5     453 110375.2759       1     394000     200     2x10-5     275.75758       1750000     1980     600     3x10-5     283.838383     2916.6       2560000     1980     600     3x10-5     254 1236.520472     135.585859     4483.3       725000     330     100     3x10-5     254 1236.520472     2196.666675     1226     66667     66667     2x10-5     510     5216.666275     1228     62700     3200     1228     62700     3200     1228     62700     3200     1228     1228     1228     1228     1228     1228     1228     1228     1228     1228     1228     1228 <td< td=""><td>462.66666</td><td>385.555556</td><td></td><td></td><td>15</td><td>18</td><td>6940</td><td>Th-228</td></td<>	462.66666	385.555556			15	18	6940	Th-228
A13000   500   200   Ax10-5   3650   1495.890411   32000000   500   200   4x10-5   3650   1495.890411   320000000   500   100   2x10-5   453   1210   2247.933884   4533.3   453000000   500   1000   2x10-5   453   110375.2759   1247.933884   4533.3   453000000   5000   1000   2x10-5   453   110375.2759   1308   3940000   2000   2000   1x10-5   1275.75758   1308   394000   2990   60   6x10-5   2757.575758   83.833383   2916.6   22600000   1980   600   3x10-5   2260.006066   483.3   2260.006066   2260.00	206	7536.585366			15	41	309000	Th-227
Sheet    Sheet    Sheet    Sheet    Sheet    Sheet    Steet    S		18.3	10				183	Ac-227
SheetI       SheetI         4130000       500       200       4x10-5       8260         5460000       600       200       4x10-5       3650       1495,890411         72720000       600       1210       2247,933884       4533,32         40000000       500       100       2x10-5       453       110375,2759         6540000       5000       1000       2x10-5       453       110375,2759       1308         394000       2000       200       2x10-5       453       110375,2759       1308         1750000       1980       600       3x10-5       2757,575758       1308         1750000       1980       600       3x10-5       883,838383       2916.6         2690000       1980       600       3x10-5       254       138,58589       4483.3         728000       330       100       3x10-5       254       1236,28689       4483.3         728000       330       100       3x10-5       510       5215,686275       2760       126,969697       1276       254       1236,29472       1276       2760       1228       1276,969697       1276       1278       1278       1276       1278 <t< td=""><td>(3</td><td>390</td><td></td><td>1x10-4</td><td>C)</td><td>51</td><td>1950</td><td>Ra-226</td></t<>	(3	390		1x10-4	C)	51	1950	Ra-226
7       4130000       500       200       4x10-5       8260         5       5460000       600       200       4x10-5       3850       1495 890411         7       2720000       600       1210       2247,93384       4533.3         9       20000000       500       100       2x10-5       453       110375,2759         1       6540000       5000       1000       2x10-5       453       110375,2759       1308         1       6540000       5000       1000       2x10-5       453       110375,2759       1308         1       6540000       2000       1x10-5       2757,575758       1308       197         1       273000       1980       600       3x10-5       2757,575758       138,383838       2916.6         5       175000       1980       600       3x10-5       254       1236,529472       1296,69697         725000       330       100       3x10-5       254       1236,529472       1296,99697         26600000       500       100       2x10-5       510       5215,686275       276         128       5270000       100       2x10-5       510       5215,686275       27	131.33333	1790.909091			15	1.1	1970	Po-210
7     4130000     500     200     4x10-5     8260       5     5460000     600     1210     2247,93384     4533,3384       7     27200000     500     100     2x10-5     1210     2247,93384     4533,3384       9     20000000     100     2x10-5     1210     2247,93384     4533,3384     4533,3384       9     20000000     100     2x10-5     453     110375,2759     276000     2000       1     6540000     5000     1000     2x10-5     453     110375,2759     1308       1     6540000     2900     600     3x10-5     2757,575768     138     2916,6       3     2680000     1980     600     3x10-5     254     1236,526472     1276,575768       3     725000     330     100     3x10-5     254     1236,526472     126,969697       725000     330     100     3x10-5     510     5215,686275     276     2196,969697       1380000     500     100     2x10-5     510     5215,686275     276     2196,969697       1380000     500     100     2x10-5     510     5215,686275     276     2196,969697       1280     520     200     2x10-	3900	26712.32877			15	219	5850000	Bi-210
7       4130000       500       200       4x10-5       8260         5       5460000       600       120       4x10-5       3650       1495.890411         7       2720000       600       1210       2247.933884       4533.3         9       20000000       500       100       2x10-5       1210       2247.933884       4533.3         9       20000000       500       100       2x10-5       453       110375.2759       1308         1       6540000       2000       1200       2x10-5       453       110375.2759       1308         1       6540000       200       1x10-5       2757.575758       197       1308         1750000       1980       600       3x10-5       2757.57578       197         172000       1980       600       3x10-5       254       1358.585859       4483.3         2800000       1980       600       3x10-5       254       1236.220472       256.00066       206.00666       254       1236.220472       254       1236.220472       2760       2196.96897       128       2760       2760       2760       2760       2760       2760       2760       2760       2760	23	707.5757576		3x10-5	200	660	467000	Bi-207
7       4130000       500       200       4x10-5       8260         5       5460000       600       1210       2247.933884       4533.3         7       2720000       600       100       2x10-5       1210       2247.933884       4533.3         9       20000000       500       100       2x10-5       453       110375.2759       1308         1       6540000       5000       1000       2x10-5       453       110375.2759       1308         1       6540000       5000       1000       2x10-5       453       110375.2759       1308         1       6540000       2000       200       1x10-5       453       110375.2758       1308         1       775000       1980       600       3x10-5       883.838383       2916.6         3       728000       330       100       3x10-5       254       1358.58585       4483.3         3       728000       330       100       3x10-5       254       1236.220472       2196.96967       254       1236.220472       2196.96967       2760       1296.96967       2760       215.865276       1228       627008276       1228       6270.08276       275.9686276		238	2				476	Pb-210
7       4130000       500       200       4x10-5       8260         5       5460000       600       1210       2247.93384       453.3         9       20000000       500       100       2x10-5       1210       2247.93384       4533.3         9       200000000       500       100       2x10-5       453       110375.2759       1308         1       6540000       5000       1000       2x10-5       453       110375.2759       1308         1       6540000       5000       1000       2x10-5       453       110375.2759       1308         1       2750000       5000       1000       2x10-5       453       110375.2759       1308         1       273000       1980       600       3x10-5       275.75758       138.83838       2916.6         3       2690000       1980       600       3x10-5       883.83838       2916.6         3       728000       330       100       3x10-5       254       1236.220472         725000       330       100       3x10-5       254       1236.220472         725000       350       250       254       1236.220472       276	2606.6666	1303.333333		5x10-5	300	600	782000	TI-204
7       4130000       500       200       4x10-5       8260         5       5460000       600       1210       2247.933884       4533.3         7       2720000       500       100       2x10-5       453       1495.890411         7       2720000       500       100       2x10-5       1210       2247.933884       4533.3         9       200000000       5000       1000       2x10-5       453       110375.2759       1         1       6540000       5000       1000       2x10-5       453       110375.2759       1         1       6540000       2000       2000       2x10-5       453       110375.2759       1         1       6540000       2000       2000       2x10-5       453       110375.2759       1         1       273000       99       60       6x10-5       2757.57578       197         1       275000       1980       600       3x10-5       883.838383       2916.6         3       2690000       1980       600       3x10-5       254       1236.28685       4483.3         3       275000       330       100       3x10-5       254       1236.	9433.3333	571.7171717		6x10-4	60	990	566000	Hg-203
SheetI 7 4130000 500 200 4x10-5 8260 5 5460000 5 50 600 200 4x10-5 8260 7 2720000 7 2720000 500 100 2x10-5 1210 2247.93384 4533.3 9 20000000 500 100 2x10-5 453 110375.2759 1 6540000 5000 1000 2x10-5 138.3333333333 2916.6 1750000 1980 600 3x10-5 2757.575758 1 7273000 1980 600 3x10-5 883.838383 2916.6 1750000 330 100 3x10-5 254 1236.220472 1750000 330 100 3x10-5 510 5215.686275 1380000 500 1000 2x10-5 510 5215.686275 1228 62700000 500 100 2x10-5 62700 3 847000 500 100 2x10-5 62700 3	1610	32200		2x10-5	100	500	16100000	Au-198
Sheet!  7 413000 500 200 4x10-5 8260  5 5460000  6 500 200 4x10-5 3650 1495.890411  7 2720000 600 100 2x10-5 1210 2247.933884 4533.3  9 20000000 500 100 2x10-5 453 110375.2759  1 6540000 5000 1000 2x10-5 1308  2 394000 2000 2000 1x10-5 1308  2 394000 2000 2000 3x10-5 2757.575758  5 1750000 1980 600 3x10-5 883.838383 2916.6  3 2690000 1980 600 3x10-5 2206.06060  3 14000 330 100 3x10-5 254 1236.220472  0 725000 330 100 3x10-5 510 5215.686275  62700000 1000 200 2x10-5 62700 3	.8	1694		2x10-5	100	500	847000	lr-192
7       4130000       500       200       4×10-5       8260         5       5460000       600       1495.890411       3650       1495.890411         7       2720000       600       1210       2247.933884       4533.3         9       20000000       500       100       2×10-5       453       110375.2759         9       20000000       5000       1000       2×10-5       453       110375.2759       1308         1       6540000       5000       1000       2×10-5       453       110375.2759       1308         1       6540000       2000       1000       2×10-5       453       110375.2759       1308         1       775000       290       60       6×10-5       2757.575758       1375.5758       2757.575758         1       1750000       1980       600       3×10-5       883.838383       2916.6         3       2690000       1980       600       3×10-5       2206.06066       483.3         3       728000       330       100       3×10-5       254       1236.220472         0       725000       330       100       3×10-5       2126.969697         0	3135	62700		2x10-5	200	1000	62700000	W-187
7       4130000       500       200       4×10-5       8260         5       5460000       600       4×10-5       3650       1495.890411         7       2720000       600       1210       2247.933884       4533.3         9       20000000       500       100       2×10-5       453       110375.2759         1       6540000       5000       1000       2×10-5       453       110375.2759         1       394000       2000       200       1×10-5       1308         197       273000       99       60       6×10-5       2757.57578         1750000       1980       600       3×10-5       883.83838       2916.6         3       2690000       1980       600       3×10-5       1358.585859       4483.3         728000       330       100       3×10-5       254       1236.220472       2196.969697         725000       330       100       3×10-5       510       5215.686275         1380000       500       200       4×10-5       516.866275	6,	1228		2x10-5	100	500	614000	Ta-182
Sheet I  413000 500 200 4×10-5  5460000 500 600 1210 2247.933884 4533.3  20000000 500 100 2×10-5  6540000 500 1000 2×10-5  6540000 2000 2000 1×10-5  725000 1980 600 6×10-5  728000 330 100 3×10-5  725000 330 100 3×10-5  510 5215.686275	39	2760		4x10-5	200	500	1380000	Hf-181
4130000       500       200       4x10-5       8260         5460000       4x10-5       3650       1495.890411         2720000       600       1210       2247.933884       4533.3         20000000       500       100       2x10-5       1210       2247.933884       4533.3         20000000       500       100       2x10-5       453       110375.2759       2         6540000       5000       1000       2x10-5       453       110375.2759       1308         394000       2000       1000       2x10-5       453       110375.2759       1308         1750000       1980       60       6x10-5       2757.57578       197         178000       1980       600       3x10-5       883.838383       2916.6         728000       330       100       3x10-5       254       1236.220472         725000       330       100       3x10-5       254       1236.220472         725000       330       100       3x10-5       2196.96967		5215.686275	510				2660000	Yb-169
Sheet I       4130000       500       200       4x10-5       8260         5460000       5460000       600       1210       2247.933884       4533.3         20000000       500       100       2x10-5       1210       2247.933884       4533.3         50000000       500       100       2x10-5       453       110375.2759       100         6540000       5000       1000       2x10-5       453       110375.2759       1308         394000       2000       1000       2x10-5       453       110375.2759       1308         175000       2000       1x10-5       1x10-5       197       197         175000       1980       600       6x10-5       2757.575758       883.8383838       2916.6         2690000       1980       600       3x10-5       1358.585859       4483.3         728000       330       100       3x10-5       2206.060606       4483.3         728000       330       100       3x10-5       254       1236.220472	7:	2196.969697		3x10-5	100	330	725000	Tm-170
4130000       500       200       4x10-5       8260         5460000       600       3650       1495.890411         2720000       600       1210       2247.933884       453.3         50000000       500       100       2x10-5       453       110375.2759         5000000       5000       1000       2x10-5       453       110375.2759         394000       5000       1000       2x10-5       1308       1308         1750000       1980       60       6x10-5       2757.575758       1358.585859       2483.3         2690000       1980       600       3x10-5       883.838383       2916.6         728000       330       100       3x10-5       2206.06066       483.3		1236.220472	254				314000	Ho-166m
\$4130000       500       200       4x10-5       \$260         \$460000       4x10-5       3650       1495.890411         \$2720000       600       1210       2247.933884       453.3         \$20000000       500       100       2x10-5       453       110375.2759         \$6540000       5000       1000       2x10-5       453       110375.2759       1308         \$394000       2000       2000       2x10-5       1308       1308         \$273000       99       60       6x10-5       2757.575758         \$1750000       1980       600       3x10-5       883.8383838       2916.6         \$2690000       1980       600       3x10-5       1358.585859       4483.3	7:	2206.060606		3x10-5	100	330	728000	Tb-160
\$4130000       500       200       \$4x10-5       \$8260         \$460000       4x10-5       3650       1495.890411         \$2720000       600       1210       2247.933884       4533.3         \$20000000       500       100       2x10-5       40000       2         \$50000000       5000       1000       2x10-5       453       110375.2759       1308         \$6540000       5000       1000       2x10-5       453       110375.2759       1308         \$394000       5000       1000       2x10-5       453       170375.2759       1308         \$273000       99       60       6x10-5       2757.575758       197         \$1750000       1980       600       3x10-5       883.8383838       2916.6	4483.3333	1358.585859		3x10-5	600	1980	2690000	Gd-153
\$4130000       500       200       \$4x10-5       \$8260         \$5460000       600       4x10-5       3650       1495.890411         \$2720000       600       1210       2247.933884       4533.3         \$20000000       500       100       2x10-5       453       110375.2759         \$50000000       5000       1000       2x10-5       453       110375.2759       1308         \$394000       2000       200       1x10-5       197         \$273000       99       60       6x10-5       2757.575758	2916.6666	883.8383838		3x10-5	600	1980	1750000	Eu-155
Sheet1  4130000 500 200 4x10-5  5460000 600 100 2x10-5  6540000 5000 1000 2x10-5  394000 2000 2000 2000 1x10-5  Sheet1  8260  8260  8260  1495.890411  1210 2247.93384 4533.3  40000 2  1308  1308	45	2757.575758		6x10-5	60	99	273000	Eu-154
Sheet!  4130000 500 200 4x10-5 8260 5460000 600 100 2x10-5 453 110375.2759 6540000 5000 1000 2x10-5 1308	10	197		1x10-5	200	2000	394000	Eu-152
Sheet!  4130000 500 200 4x10-5 8260  5460000 500 600 100 2x10-5 453 110375.2759	39	1308		2x10-5	1000	5000	6540000	Sm-151
Sheet!  4130000 500 200 4x10-5 8260 5460000 3650 1495.890411 2720000 600 1210 2247.933884 4533.3 20000000 500 100 2x10-5 40000 2		110375.2759	453				50000000	Pm-151
Sheet! 4130000 500 200 4x10-5 8260 5460000 500 500 3650 1495.890411 2720000 600 1210 2247.933884 4533.3	2000	40000		2x10-5	100	500	20000000	Pm-149
Sheet! 4130000 500 200 4x10-5 8260 5460000 3650 1495.890411	4533.3333	2247.933884	1210		600		2720000	Pm-147
Sheet1 4130000 500 200 4x10-5 8260		1495.890411	3650				5460000	Pm-145
Sheet1	206	8260		4x10-5	200	500	4130000	Nd-147
				Sheeti				

	1020	333	267	150				333		333		267	267	89	333	299	299	164
	¥	38.53333333	75666.66667	•				126.3333333		47.13333333		47.06666667	2166.666667		85.33333333	45.86666667	45.86666667	
	318.75	18.0625	57178.84131	86.53846154	49.75	48.46666667	48.46666667	32.67241379	46.8125	37.21052632	25.10344828	37.15789474	637.254902	48.57142857	55.65217391	36.21052632	36.21052632	63.07692308
	32		397		16	15	15	1160	16		29							
Sheet1																		
	10	15	300	15		128		300		15		15	15	15	15	15	15	15
		32		26						19		19	51	21	23	19	19	39
	10200	578	22700000	2250	196	727	727	37900	749	707	728	902	32500	1020	1280	688	688	2460
	11-238	Nn-237	Nn-239	Pu-236	Pu-238	Pu-239	Pu-240	Pu-241	P11-242	Am-241	Am-242m	Am-243	Cm-242	Cm-243	Cm-244	Cm-245	Cm-246	Cf-252